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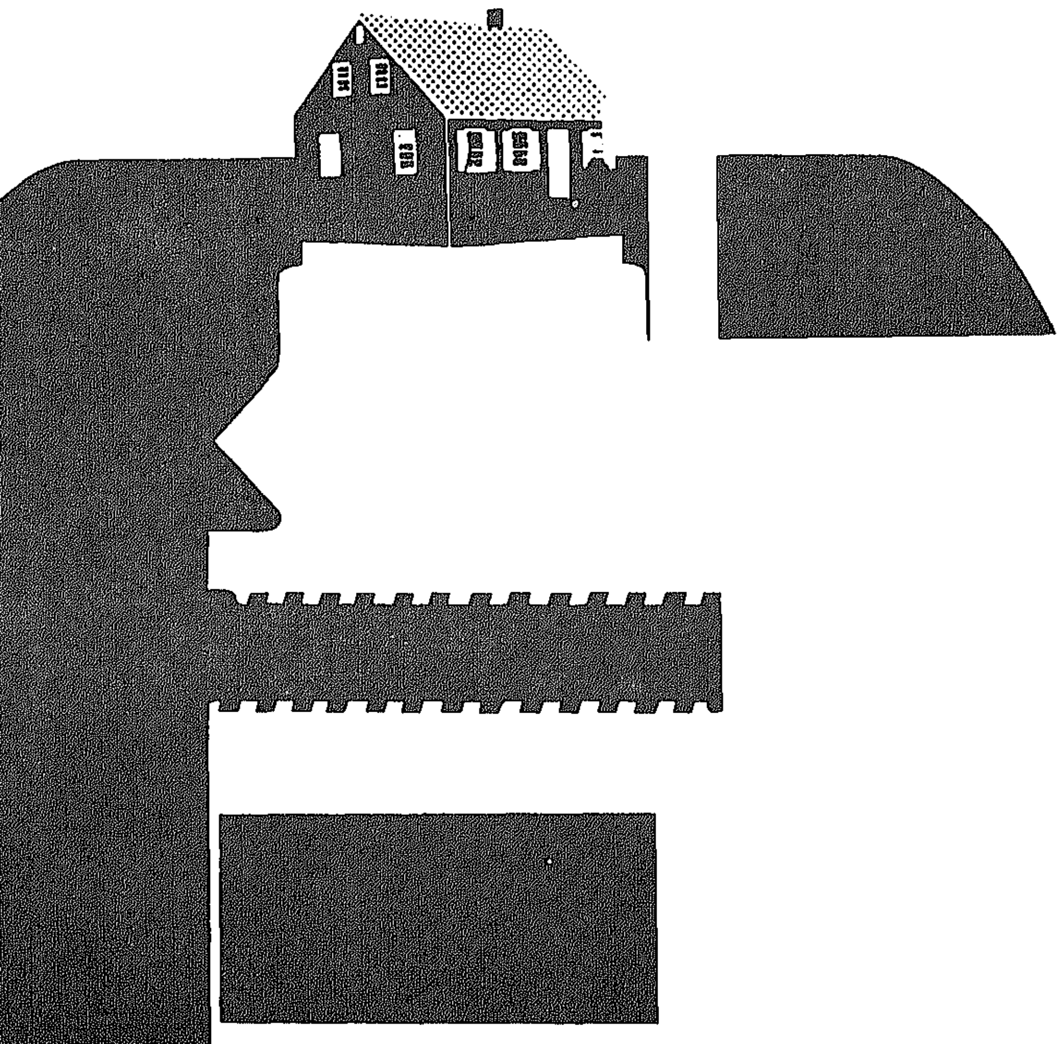


REMEDIAL MEASURES FOR HOUSES DAMAGED BY EXPANSIVE CLAY

April 5, 1978

by

The University of Texas at Arlington
Under Contract No. H-2240-R

for

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

FOREWORD

This report addresses a housing problem that is most prevalent in
outhwestern region of the United States; cracking of floors and
 caused by swelling and shrinking of the soil on which the house is
. Laboratory and field investigations of five repair techniques
on damaged houses in two geologic formations composed primarily of
sive clay are documented in the study. Results of a 2-year
ation of the effectiveness of the various techniques indicate
damage caused by swelling and shrinking can be minimized by treating
lab and soil as an interactive system.

The information contained in this report should be of use both to
wners and to professionals who must recommend repair procedures to
wners. It was developed with the assistance of three Government
ical Representatives: William J. Werner (deceased) Conrad Arnolts,
onald J. Morony.

Donna E. Shalala
Assistant Secretary for Policy
Development and Research

ACKNOWLEDGEMENTS

his research documents the performance of certain remedial measures could be utilized as repair techniques, along with other actions, to e homes damaged by the vertical movement of expansive clay soils. gnitude of movement is associated with the type of clay minerals in il and seasonal climatic conditions.

he University of Texas at Arlington is indebted to the Department of g and Urban Development for sponsoring this, and parallel research, may be utilized to refine repair procedures to restore homes and light buildings which are in a damaged condition. The Southwestern States has climatic conditions which allow the shrink and swell ties of expansive soils to develop with devastating effect. How- other areas of the United States and the world are not immune. the soil moisture conditions be significantly altered in other areas soils include clay minerals of the montmorillonite group, volume of the soils may be expected. Damaged to man-made structures may from unsightly cracks to facilities which are structurally unsound. structive mechanism is a time-dependent process unlike damage as- ed with a natural disaster. However, costs of repair or replacement as great or greater. Fortunately, unlike a natural disaster, or destruction associated with expansive soils does usually not in- loss of life.

any individuals have contributed to this research during various or throughout the project duration. While it is impossible to recog- veryone associated with this research, there are those whose efforts buted immeasurably. These individuals include:

r. Henry F. (Jeff) Ball, H.U.D., Dallas Area Office, Dallas, Texas

r. Paul J. Wright, Vice President, Woodbine Corporation, Fort Worth, Texas

r. Ernest L. Buckley, Professor of Architecture

rs. Judith B. Corley, Civil Engineering Graduate Student

r. William J. Howard, Civil Engineering Graduate Student

r. James M. Sims, Civil Engineering Graduate Student

r. Abbas Mehdibeghi, Civil Engineering Graduate Student

r. Weerapun Sriboonlue, Civil Engineering Graduate Student

Special recognition must be given to Mr. Wallace A. Clines, Tec
Staff Assistant, whose special abilities and unstinting hours did mu
insure timely completion of each project phase. To all other people
in any way contributed to this research, the author expresses his si
appreciation.

Mr. William J. Werner, P. E., (deceased), Office of Policy Devel
and Research, Department of Housing and Urban Development, served as
Government Technical Representative until May 5, 1978. Mr. Conrad A
became the Government Technical Representative and served during the
mainder of the research period.

Arthur R. Poor, Ph.D., P.E.
Professor of Civil Engineering

PREFACE

his report is subject to the following limitations:

1. The two year time span of the data collection is rather short.

2. There is additional data collection in progress which could possibly alter the conclusions regarding the effectiveness of the techniques studied.

3. Caution should be exercised in drawing general conclusions based upon a single experiment. Each remedial procedure was tried only once in each geologic formation.

4. Successful application of any of these remedies depends heavily upon the knowledge and skill of the contractor. Not only is it necessary to determine the correct quantity of water to be added, but also the proper locations for adding the water. For example, cupped and domed slabs would be treated differently.

Title | Page

A B S T R A C T

Remedial Measures for Houses Damaged by Expansive Clay S laboratory and field investigations of various repair techniq on two geologic formations whose residual soils are predomina clay. Five damaged homes on each formation were identified a stabilization techniques utilized for the foundation soils. had concave and convex curvatures, with corresponding damage flected in the superstructure.

The effectiveness of various repair techniques to mitiga change in underlying soils with the slab and subsoil acting a entity were evaluated. Materials and equipment commonly avai industry were utilized.

Moisture-temperature cells were installed in boreholes a of each side of the house slab and calibrated for existing so Leveling points were inserted around the slab perimeter, with vations referred to a permanent bench mark. Bench marks were each of the ten homes for accurate determination of slab diff ments. Data acquisition of soil moisture, temperature, and v ment was continued over four seasonal climatic cycles, or app years.

Results indicated damage to a home resulting from founda swelling and shrinking can be minimized by treating the slab interacting system. By establishing the water content of the soil at 2-3 percent above the Plastic Limit of the soil and i soil mass or maintaining this moisture content, the volume ch seasonal weather cycles would be reduced to a minimum.

expansive clay soils in the Southwest United States and in
ar the Dallas - Fort Worth Metroplex are detrimental to successful
nce and behavior of single family residences and other light con-
n constructed on concrete slabs-on-ground. The combination of
ary clay deposits containing significant quantities of Montmorillonite
and a semi-arid climate permit volume changes in the soil which can
antly damage or result in a structurally unsound residence.

s report documents the behavior of 10 residences at various locations
he Dallas - Fort Worth Metroplex. All houses were identified by
D. Dallas Area Office and were selected from a group of H.U.D.
uses that showed evidence of foundation/superstructure failure due
nal soil movements. Five houses were founded upon the Eagle Ford
rmation, and the other five were founded upon the Taylor Marl
n, both very active soils. Other reports which are considered
l to the information contained herein are:

"Interim Report of Remedial Measures for Houses Damaged by
e Clay," October, 1975 (HUD - PDR - 131).

"Interim Report of Remedial Measures for Houses Damaged by
e Clay," November 1976 (HUD - PDR - 172-(a)).

same remedial technique was utilized for houses located on the
erent geologic formations. Five different techniques were utilized
strate effective use of commonly available materials and equipment
re a house to a useable condition.

Two distressed houses on different geologic formations were used
mine the effectiveness of utilizing high pressure lime slurry
n procedures to stabilize the foundation soil.

Two houses utilized a vertical capillary barrier of coarse lime-
inhibit or minimize moisture migration.

Two houses utilized a vertical barrier of lean concrete to isolate
mass and mitigate moisture migration.

Two houses utilized a vertical barrier made from a formulation
lt and ground-up rubber tires to inhibit moisture movement.

Two houses utilized a buried subsurface irrigation system to
a stable moisture content in the subsoil.

The subsurface soils at each house were instrumented wit temperature cells in a borehole located approximately one foo house wall. The first instrument was located approximately c the perimeter beam and another instrument placed every 18 inc four instruments were installed. The borings were located at of each side of the house (16 instruments per house).

Permanent leveling inserts were placed in the perimeter each house to determine vertical movements with time. All el referred to a permanent bench mark installed in the project a

Data acquisition and evaluation has continued for two ye seasonal climatic cycles. In this minimal time period, certa conclusions are given.

a. The addition of water to foundation soils will not eliminate prior movements associated with shrink and swell ac

b. Vertical barriers which isolate a substantial soil useful techniques to restore damaged homes to a useable confi with the barrier is the desireability to raising the moisture the subsoil approximately 2-3 percent above the soil plastic

c. For fissured expansive clay soils, data indicate th pressure lime slurry injection techniques are not a competiti technique.

d. Passive systems for soil stabilization are desireab quently, the use of a subsurface irrigation system should not further at the present state-of-the-art.

This research study was made possible by the Office of P and Research, Department of Housing and Urban Development. D will be continued for another year or two additional climatic broaden the data base at which time an updated report will be Further data acquisition will be dependent upon instrument li rates this far have been minimal.

REMEDIAL MEASURES FOR HOUSES DAMAGED

BY EXPANSIVE CLAY

Section 1

INTRODUCTION

POSE AND SCOPE

s report is in response to the requirements specified as item 1 eports of Work, Final Reports, Phase 1 and 2, Attachment 1, to Contract ; "Contract for Research and Demonstration of Remedial Measures and Foundation Design of Houses on Expansive Clay Soils."

vious reports documenting actions of this research project and which ntial references to this final report are:

"Interim Report of Remedial Measures for Houses Damaged by e Clay," October, 1975(1) This report documented results of d tasks in the referenced Statement of Work, as follows:

Task 2 required field sampling of the soils in the vicinity of each of the 10 houses.

Task 3 activities included laboratory support and determination of soil properties.

Task 4 included the field surveys for existing conditions of the dwelling, installing instrumentation, installing leveling points around the house perimeter and for installation of a permanent bench mark for data reference.

"Interim Report of Remedial Measures for Houses Damaged by e Clay," November, 1976(2). This report documented results of d tasks in the referenced Statement of Work, as follows:

Task 5 required stabilizing the foundation soil utilizing high pressure lime slurry injection procedures. Two distressed houses on two different geologic expansive soil formations were considered.

Task 6 activities included the use of different type barriers to minimize moisture migration. For two different geologic formations,

sisting of coarse sand and gravel. Two houses had a v
moisture barrier composed of lean concrete, and two ho
utilized a vertical moisture barrier made from a formu
asphalt and ground-up rubber tires.

3. Task 7 involved maintaining a stable moisture content
foundation soil by means of a subsurface irrigation sy
Two houses on two different geologic expansive soil fo
were considered.

This final report documents the results of Phase I. Includ
acquisition, analysis, and performance parameters of the various
tion techniques used in limiting the volume change in expansive
jected to climatic moisture and temperature cycles.

The primary objective of Phase I of this research contract
investigate various remedial techniques which could be used to r
houses damaged by foundation movements to a useable condition.
proposed techniques must demonstrate effective use of commonly a
materials, equipment presently manufactured and/or having a capa
being modified, and being economically justified on a long term
has been established that the stabilization of expansive clay so
necessary to accomplish this objective. The soil stabilization
anticipated to limit volumetric change in the subsoil caused by
climatic cycles.

1.2 BACKGROUND

The work that is being carried out under this contract was
developments in applied structural and geotechnical theory that
by the Construction Research Center at the University of Texas a
The cooperative efforts of the Civil Engineering Department and
Architecture, in close coordination with some of the leading hom
the Dallas Fort Worth metropolitan area, have produced a better
of the factors that contribute to foundation performance.

Phase I of the research contract involved corrective measur
to a carefully selected sample of 10 existing H.U.D. owned house
evidence of foundation/superstructure failure due to seasonal so
All houses were identified by the H.U.D., Dallas Area Office. F
were founded upon the Eagle Ford Shale formation, and the other
upon the Taylor Marl formation; both very active soils. Both fo
of residual clay soils from the Geologic Gulf series of the Creta
are neritic marine deposits. Volcanic materials were prominent a
was widespread at many levels.

The residual clay soils were highly plastic and possessed the capacity rge volume change with changes of climate and soil moisture. These sirable features were stipulated parameters for selection of the ten hous tested.

Remedial measures that could be used by the owner of an existing house to structural distress, or to apply as a part of a repair project, have bee lated and performance data over two years given. Phase II of this contra des performance data on experimental foundation design and construction.

OF SUBSURFACE SOIL

2.1 MOISTURE-TEMPERATURE CELL INSTALLATION LOCATIONS[1]

Moisture-temperature cells were installed in four borings for
ten test houses. The north (or most northerly) boring was always
numbering continued consecutively, clockwise around the house. A
boring code was used during field operations to insure correct loc
first character was the boring number as previously described. Th
character was an upper case letter representing the compass direct
ponding to the boring number. The third character was the moistur
cell number. The moisture-temperature cell numbers ranged from Nu
Number 4. As an example: 4W2 corresponds to boring number 4, wes
house and instrument number 2, which was 2.5 feet below the grade
addition to these borings, a fifth instrumented boring was made at
lected for treatment by the lime slurry-pressure injection process
borings were made outside the perimeter of the injection grid and
the sunny west side of the house.

2.2 MONITORING MOISTURE-TEMPERATURE CHANGES

The installation of moisture-temperature cells allowed contin
toring of the subsoil moisture and temperature changes at the peri
test houses. Initial moisture contents were determined at all loc
to beginning any corrective measures. Data acquisition for moistu
ture and vertical movement of foundation soil continued through ap
four seasonal cycles or March, 1978. Comparative data analysis wi
the effectiveness of each soil stabilization technique.

2.3. LABORATORY CALIBRATION

Individual moisture-temperature cell calibration curves were
each of the 10 house locations in the Phase I portion of the proje
calibration was performed simultaneously for the 11 slabs in the P
of the project. Undisturbed three inch cores were obtained from t
the field at the same depths that the moisture-temperature cells w
stalled and were placed in a "jig" and split longitudinally using
A moisture-temperature cell was placed between the two halves of t
the core was then securely vised back together. A sample from the
to determine the initial moisture content, and the sample was weig
dry weight could be calculated. The core was then securely taped
tape and placed inside a nylon mesh cut to fit the length of the c
insured a confining effect while allowing for uniform evaporation

The core was submerged in distilled water for about 48 hours to allow for ete saturation of the soil, and at the end of this period, the excess ure was removed from the leads and nylon mesh. The sample was then weigh termine the moisture content and a resistance reading was made on the cel

The sample was allowed to air dry for approximately four hours, and a d of 20 hours was allotted for equalization of the moisture content of th During the equilization period, the core was stored in a controlled ity environment. After the moisture equilization period, the core was ed to determine the moisture content, and resistance and temperature read were taken. The resistance readings generally increased with decreasing ure content.

The pattern of air drying, equalizing, and resistance readings was re- d until the maximum resistance reading for the ohmmeter was obtained or further drying was likely to cause excessive spalling of the soil upon r ation. The samples were generally recycled if the moisture content dropp five percent. At this point, the core was submerged for 48 hours, and a rying cycle was begun.

At least two, and usually three or more, cycles of wetting and drying wer rmed for every core. The decision to stop readings on core was based on ter calibration output. A total of 24 cores was used in producing cali- on curves for the 10 sites in Phase I.

COMPUTER CALIBRATION

Previous work with moisture temperature cell calibration indicated that ration curves resulted in a linear semi log plot for each log cycle when tance was plotted on the logarithmic scale and moisture content on the netic scale.

The linear line segments for each log cycle were fit using the method of squares. The two defining equations for a least squares curve are:

$$\sum_{i=1}^{n} y_i = nk_o + K_1 \sum_{i=1}^{n} x_i$$

$$\sum_{i=1}^{n} x_i\, y_i = k_o \sum_{i=1}^{n} x_k + k_1 \sum_{i=1}^{n} x_i^2$$

y is the moisture content at the next highest log boundary, x is equal to

$$k_1 = MC(J + 1) - k_0$$

The values of k_0 and k_1 can be used to define a straight line u
data of daily calculated moisture content resistance readings.
these values are called A1 and A2 and were equal to the followi

$$A1 = \frac{(\Sigma MC_i^2) - (\Sigma \text{ Resist}_i^2) - (\Sigma \text{Resist}_i \times MC_i)\ (\Sigma \text{ Resis}}{(\text{Number of Points})\ (\Sigma \text{ Resist})^2 - (\Sigma \text{ Resist})^2}$$

$$A2 = \frac{(\text{Number of Points})(\Sigma \text{ Resist}_i \times MC_i) - (\Sigma MC_i)(\Sigma \text{ Res}}{(\text{Number of Points})\ (\Sigma \text{ Resist}^2) - (\Sigma\text{Resist})^2}$$

The moisture content at the boundaries of each log cycle f
squares straight line could then be calculated. The higher end
squares line was equal to A1 + A2 * (I + 1) and the lower end w
I is the power of ten for the log cycle being considered.

The general sequence of the calibration program CALIB was·

1. Read in the number of data points in each log cycle,
   being 10^6 and the lowest 10^2.

2. Test to see if there were any data points in the firs
   10^6. If not, test the next log cycle, and continue u
   cycle having data is found. Calculate the values of
   straight line for this data at the two endpoints.

3. Go to the next lower log cycle and fit the least squa
   line. Calculate the values at the two end points. C
   cycles have been completed.

4. Average the values at the end points for which two va
   culated. For example, if there were data points in t
   then 1 x 10^6 is the lower limit of this cycle and a v
   content at this point would have been calculated base

the range 10^6. However, 1×10^6 is also the upper limit for data points in the log cycle 10^5, so a value of moisture content woul have been calculated based on data in the range 10^5. These two values would have been averaged so that a single curve made up of connected straight line segments was obtained.

5. The 95% prediction interval was approximated as being 2* sigma fo data in each log cycle. The end points of the prediction interva were also end justified by averaging.

Output consisted of the values of the end points based on the least sq ve fit, the end justified values of moisture content and the log boundar the upper and lower limits of the prediction interval at the log boundar additional calculations were necessary in order to plot the calibration

Laboratory calibration was continued for a core until the computer cal n indicated that the recycling process was fairly stable. This was done ning the program CALIB for data from each drying cycle and comparing the nts for each log boundary. Errors in input and poor soil contact betwee and the core could usually be detected from the computer results. For nple, Table 1 shows the end points obtained from Sample # 23, Lewisville Phase I. The variation in end points obtained for cycle 1 is attribute contact between the cell and the core for the first cycle.

The problem of sample size was a continuing problem, with the smallest oer of samples being in the range of 10^1 and 10^2, and 10^6. More deviatio veen cycles was tolerated for these end points than for those having lar ole sizes. Table 1 indicates the number of data points per log cycle fo house location for the samples used on Phase I and the number of dryin es before an individual sample was considered stable.

Also listed in Table 2 is the number of days of data collection per co average number of days represented almost 3.5 months, and this excessiv bration period required readings to be taken 7 days per week.

The variation in values obtained from the various cores was attributed following factors:

1. Limited sample size and deviation in sample size.

2. Variation in sample material with depth. Samples were located at depths between 0.5' and 13.5', and all were taken from the same bo

3. Some samples showed poor contact between the cell and the soil for initial cycle.

4. Slaking of material was noted in cases where the core became excep

Based on prior experience in the calibration of the moisture and tempera-
re cells, satisfactory laboratory calibration can be obtained by subjecting
res into which the cells have been implanted to cycles of saturation and
ying. The results obtained by use of a program such as a CALIB were useful
th in terminating individual core calibrations and in plotting the final re-
lts.

Time requirements for laboratory calibration and by the limited accuracy
the field installed cell would limit their use except in large installatio
data was available concerning the failure rate of the field cells, or on t
riability in field readings due to cell characteristics.

5 SUBSURFACE MOISTURE-TEMPERATURE DATA ACQUISITION

The acquisition of data was planned to coincide with the acquisition of
evation data. Plug in connectors were installed in weather proof boxes on
ch side of the house foundation, and the instrument leads from the borings
neath the center of the house were carried to one side of the foundation.
w data was acquired by using a read-out box modified to accommodate the num
instruments in each borehole. The data, given in resistance values, were
corded and reduced to meaningful values of moisture and temperature in the
boratory.

The master Calibration Curves for the 10 houses included in Phase I of t
oject are given in Figures 1 through 10. The variation of soil moisture an
mperature with time and depth below the slab grade beam will be discussed i
e section relating to the particular stabilization technique used.

ENDPOINTS FOR CALIBRATION CURVE

Sample #23 Eastwood St., Lewisville

Depth 4.5 - 6.0 ft.

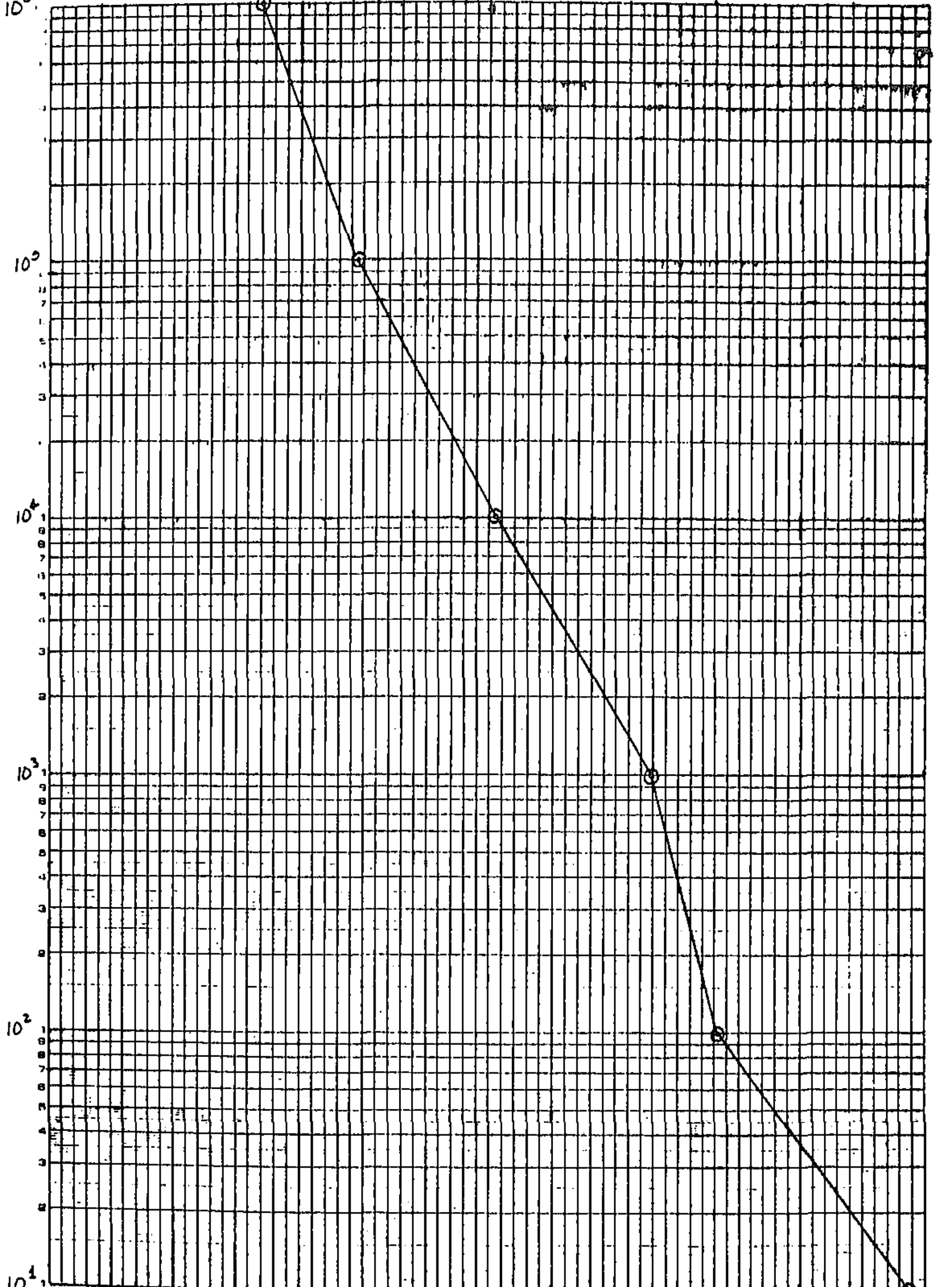
10^6	10^5	10^4	10^3	10^2	Cycle #
0.00	1.73	6.80	21.05	27.67	1
3.52	14.34	18.60	24.21	28.80	2
4.78	12.15	18.92	25.57	28.99	3
4.16	11.81	18.63	25.98	28.90	4
3.95	8.80	11.88	23.90	28.53	Combined

TABLE 2

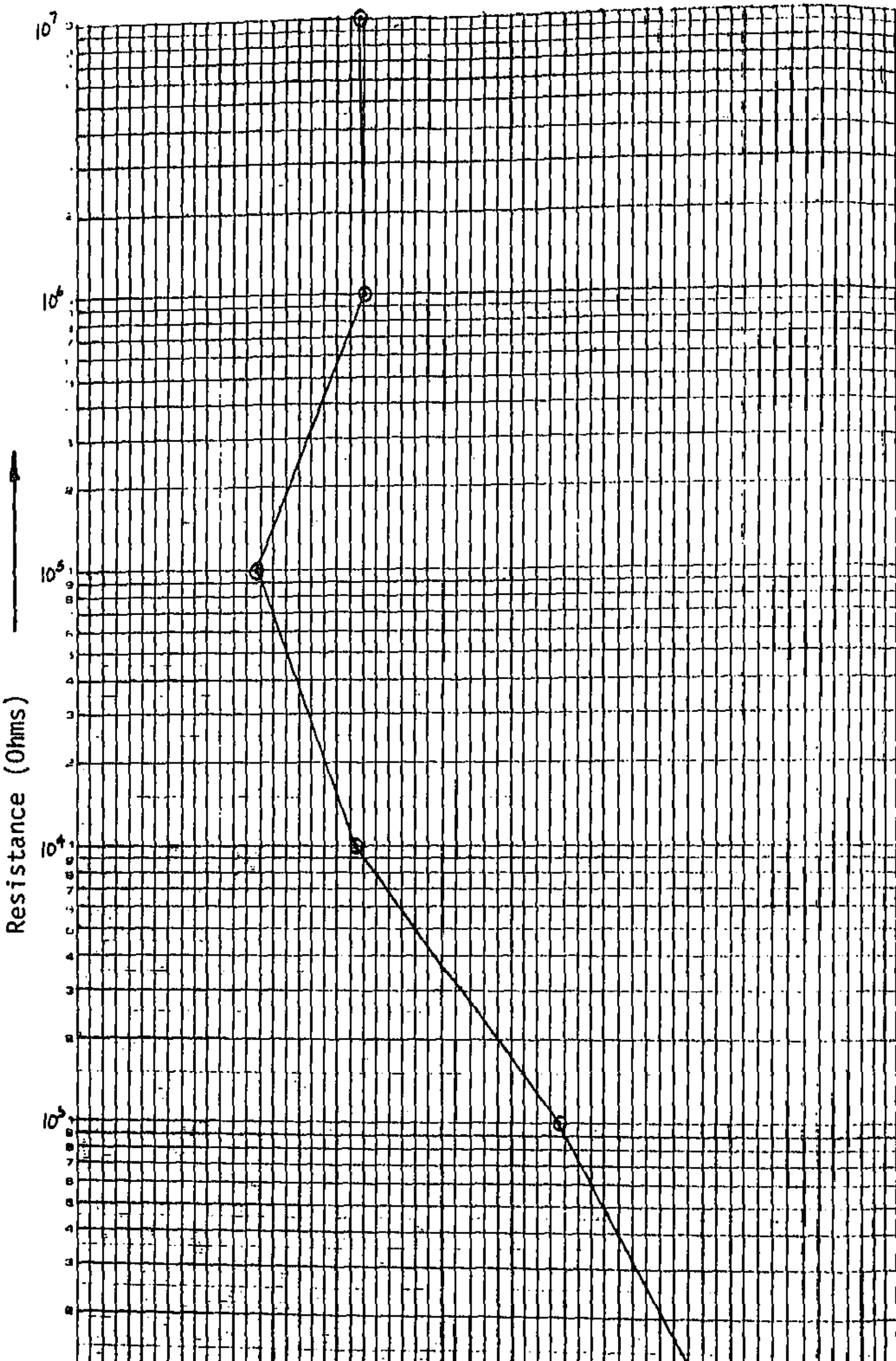
DATA POINTS PER SAMPLE

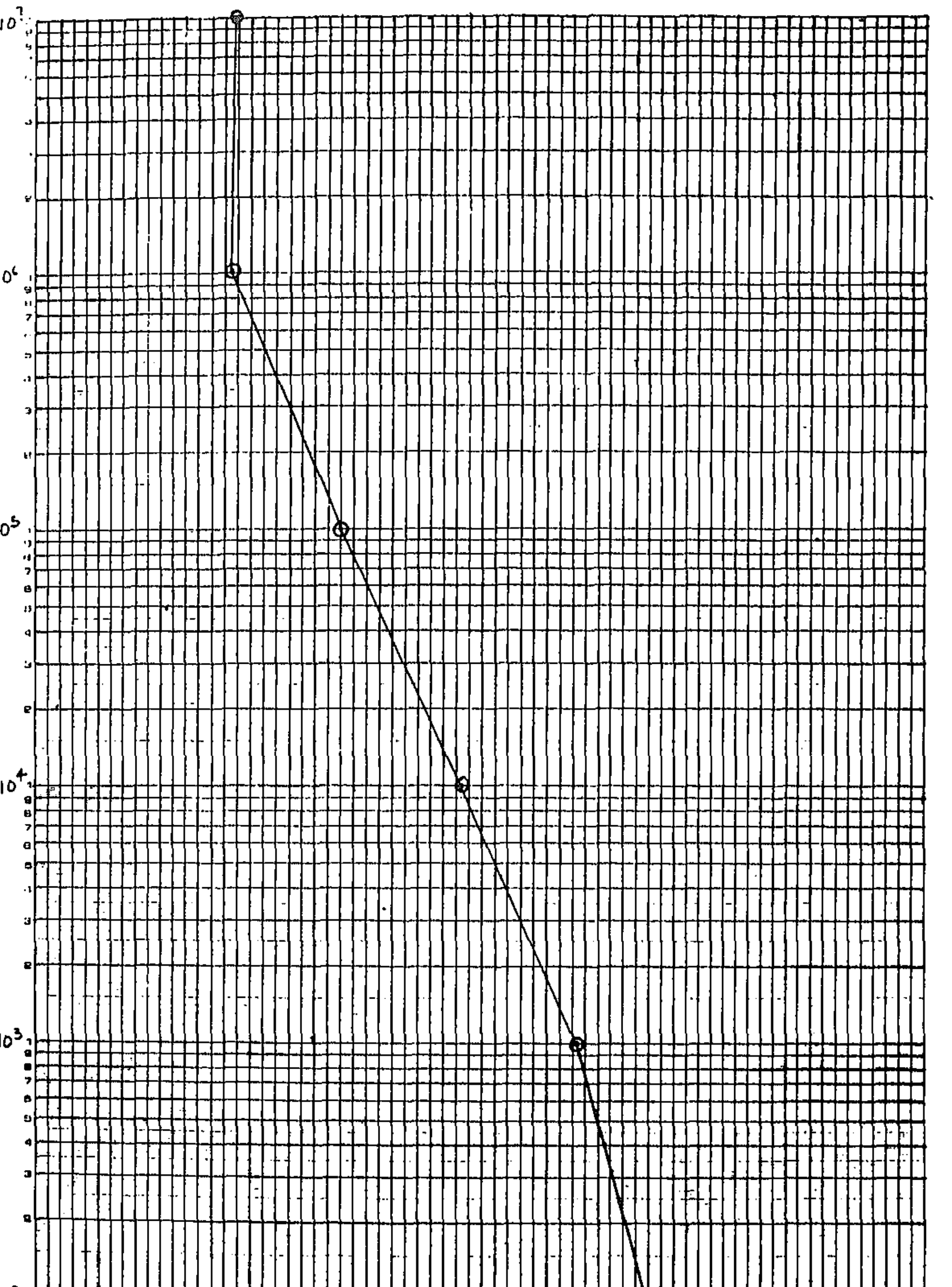
Location	Sample #	10^6	10^5	10^4	10^3	10^2	# Cyc
Eastwood Lewisville	12	17	20	14	18	6	3
	23	18	30	35	32	15	4
	33	4	4	1	2	2	1
Cedar Keys, Lewisville	13	29	46	18	14	6	3
	24	39	46	26	29	15	6
Sweetbriar Lewisville	14	38	34	41	14	12	4
	25	0	57	11	12	9	2
Cary Drive Mesquite	15	21	38	15	12	6	3
	26	17	40	24	22	8	3
Heath Street Mesquite	16	21	47	17	12	5	4
	27	23	47	14	15	12	5
Athens Street Mesquite	18	16	46	32	19	10	5
	32	27	30	7	11	9	4
Fess Street Dallas	4	12	29	26	20	16	4
	5	23	54	18	11	4	2
	6	19	42	15	24	6	6
N.E. 32nd St. Grand Prairie	9	16	30	15	14	7	4
	10	43	45	27	20	12	5
	11	21	55	24	30	9	5
Culmer Street Balch Springs	17	29	47	21	23	8	5
	31	25	19	14	13	9	3
Bluffcreek Dallas	19	14	32	15	18	8	4
	28	31	61	17	5	11	2
	34	20	14	5	9	5	2

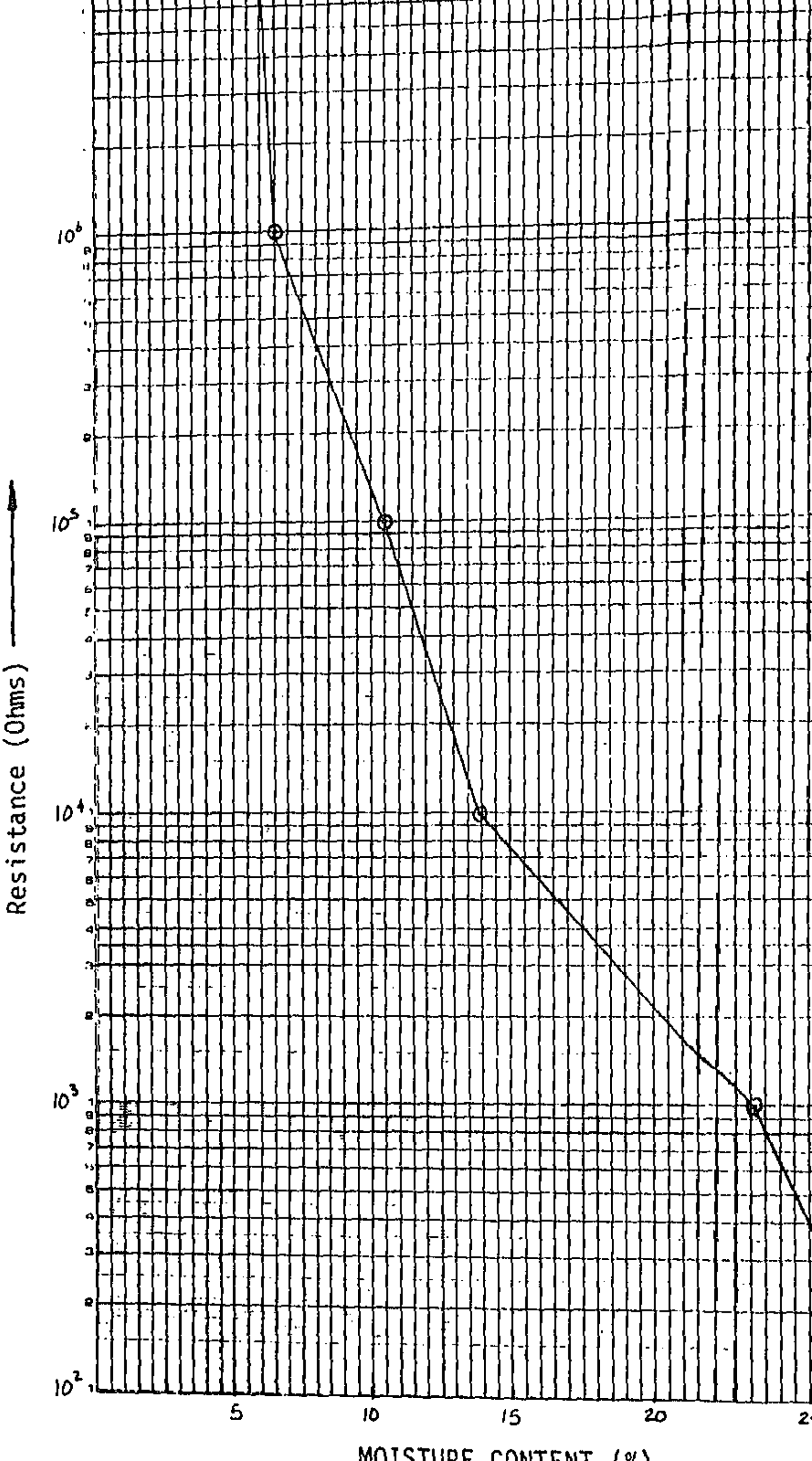
Average Number of Samples Per Location : 2
Average Number of Days Per Sample : 104
Average Number of Cycles Per Sample : 3

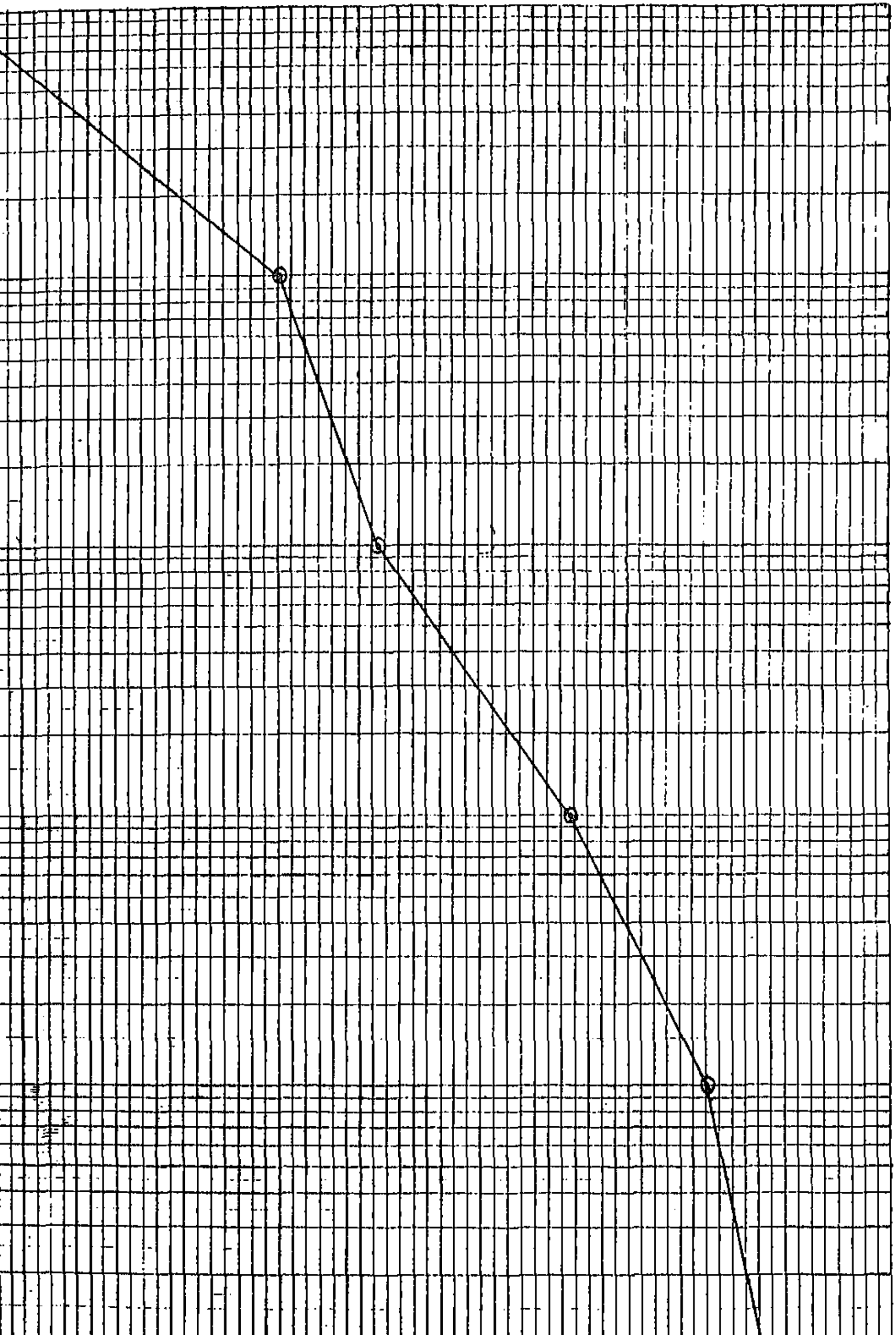


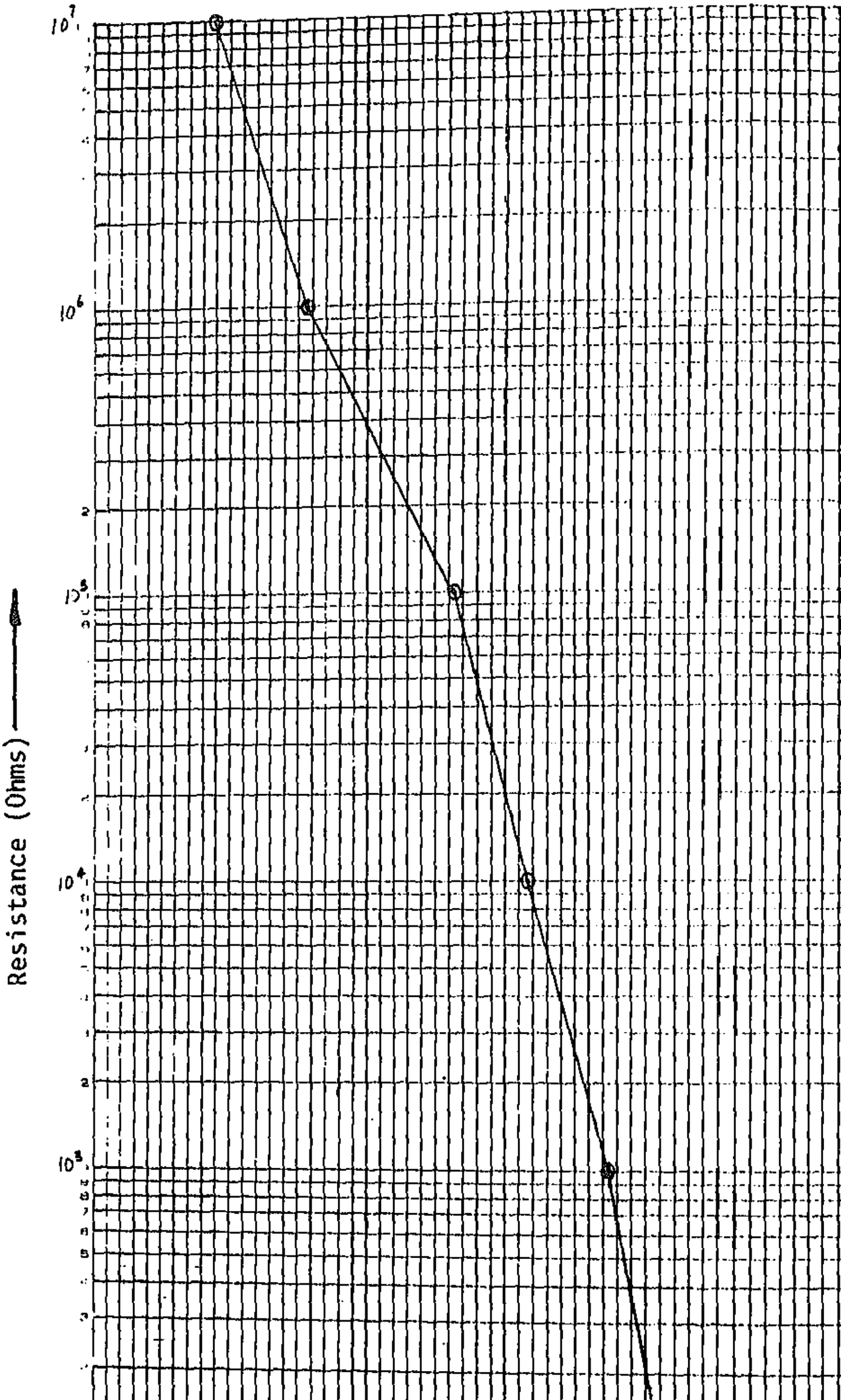
10^6
10^5
10^4
10^3
10^2
10^1


Resistance (Ohms)
10^7
10^6
10^5
10^4
10^3

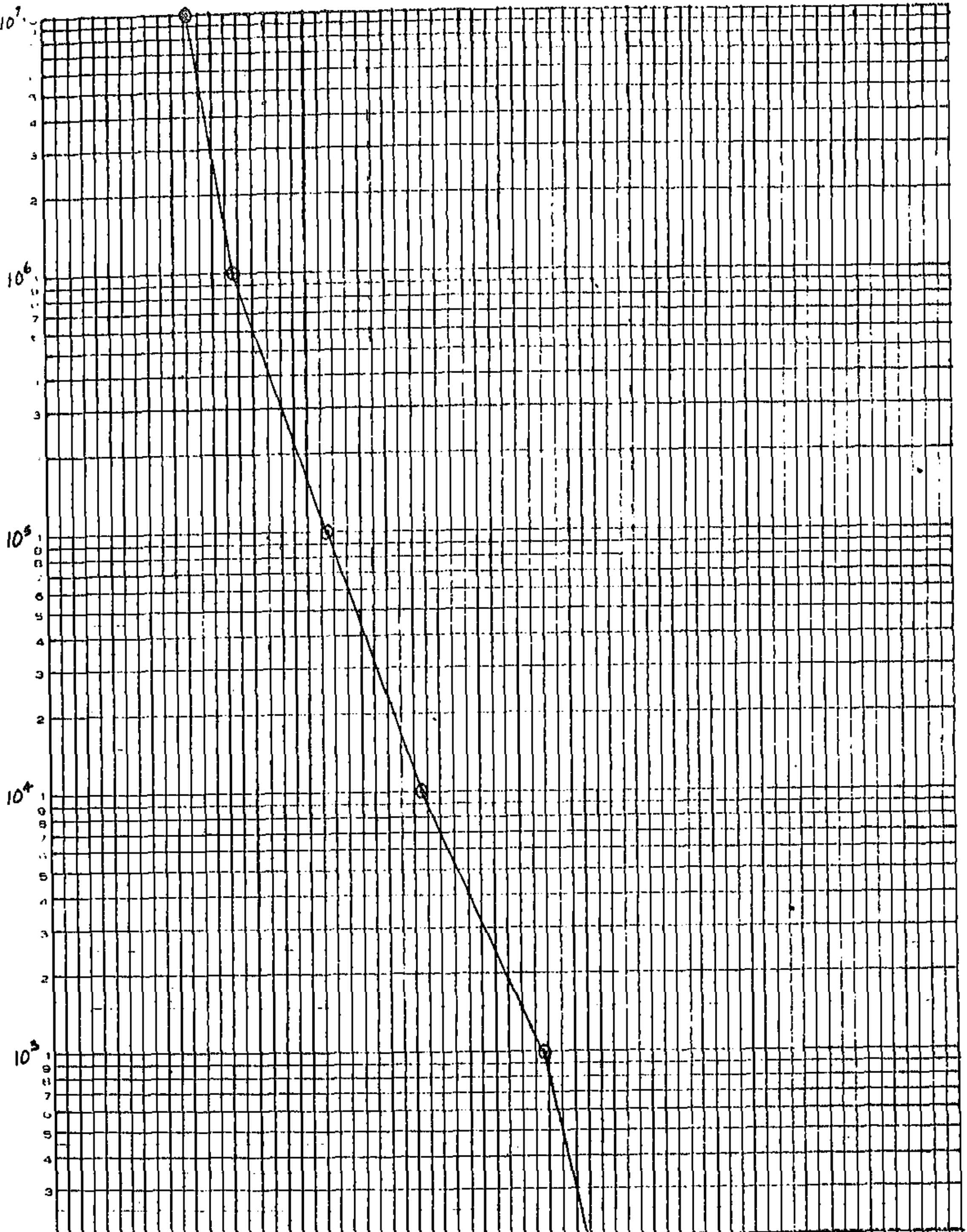

10^7
10^6
10^5
10^4
10^3

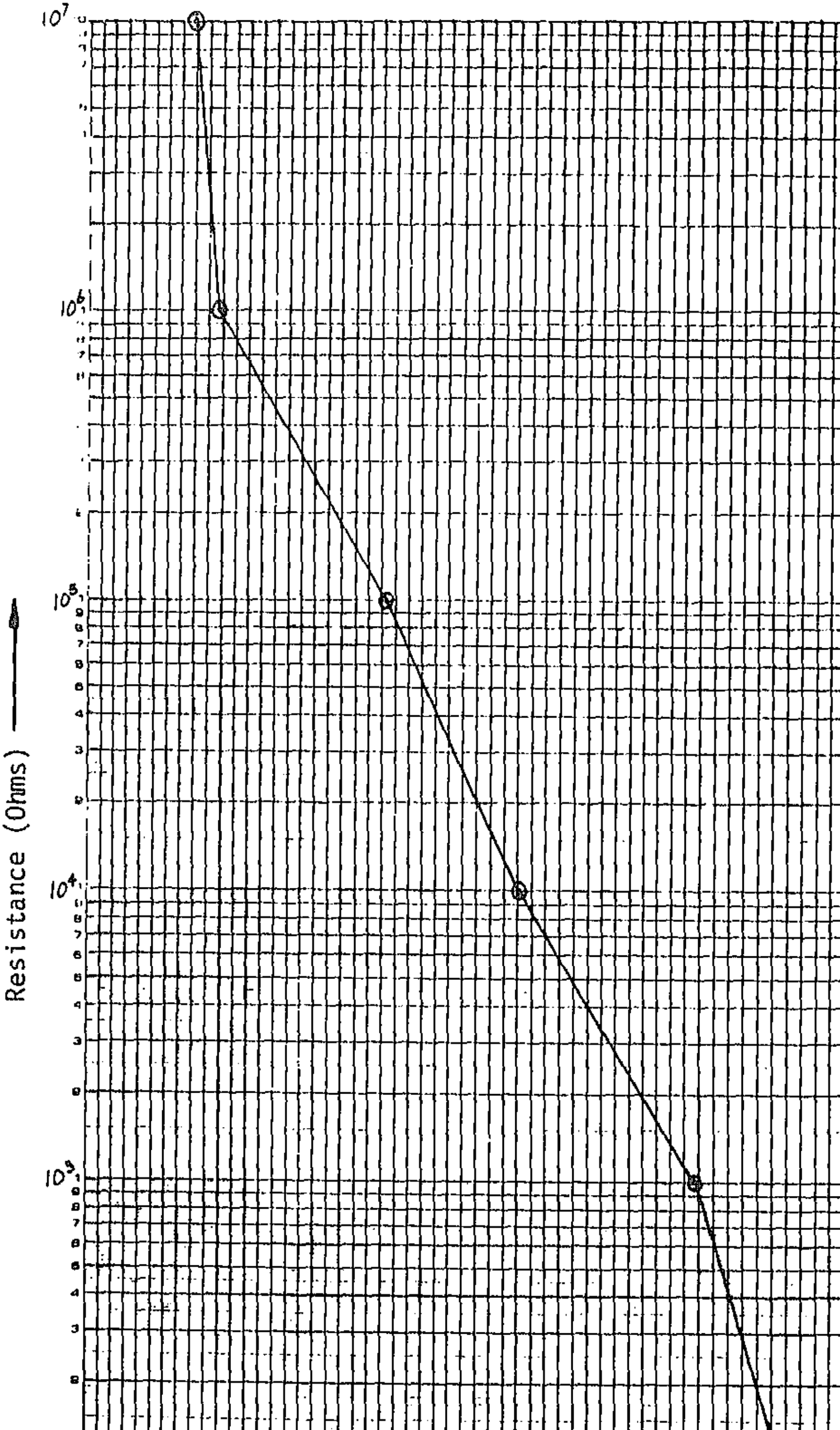

Resistance (Ohms)
10^6
10^5
10^4
10^3
10^2
5
10
15
20
MOISTURE CONTENT (%)



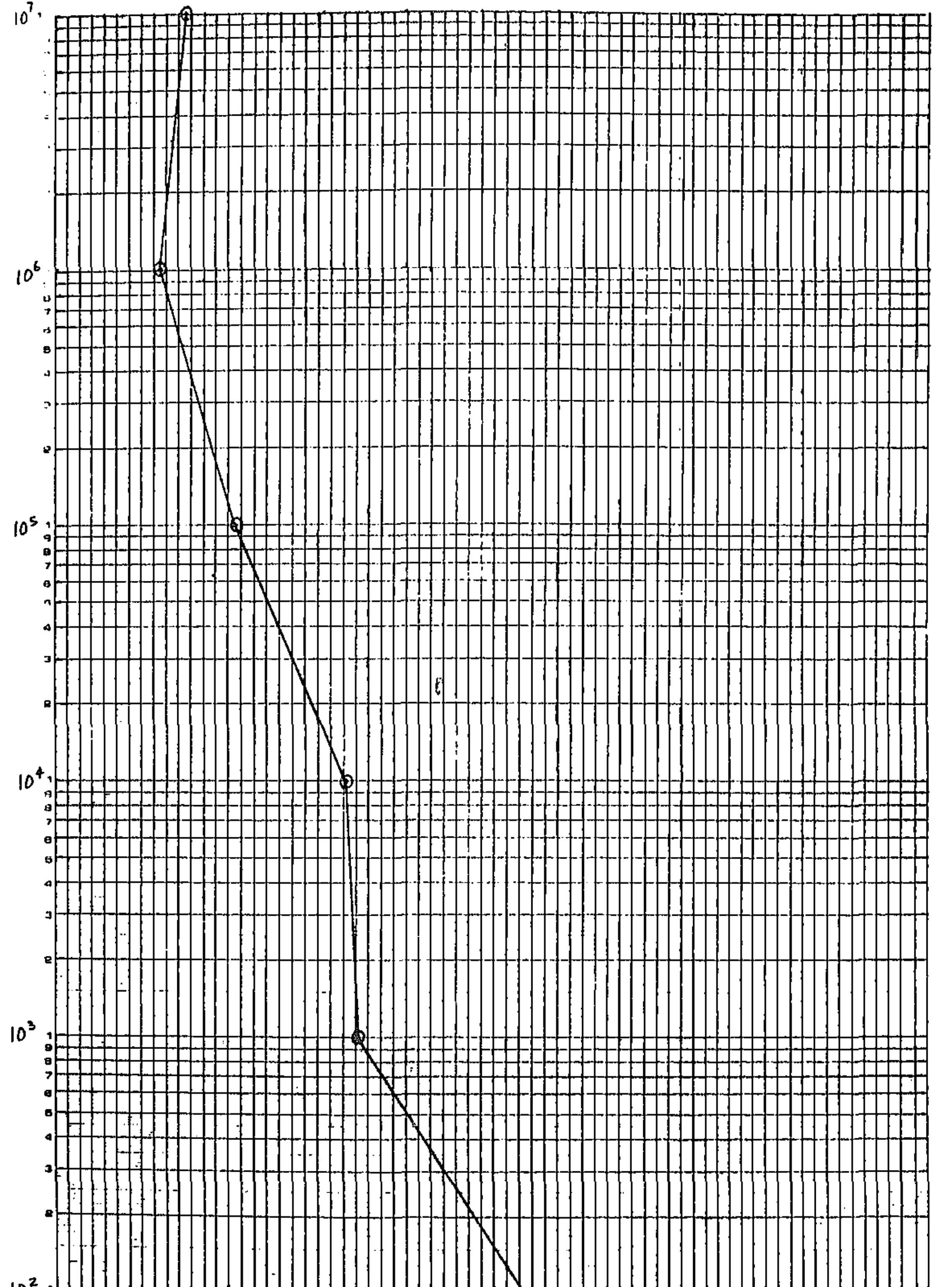


Resistance (Ohms)
10^7
10^6
2
10^5
10^4
2
10^3

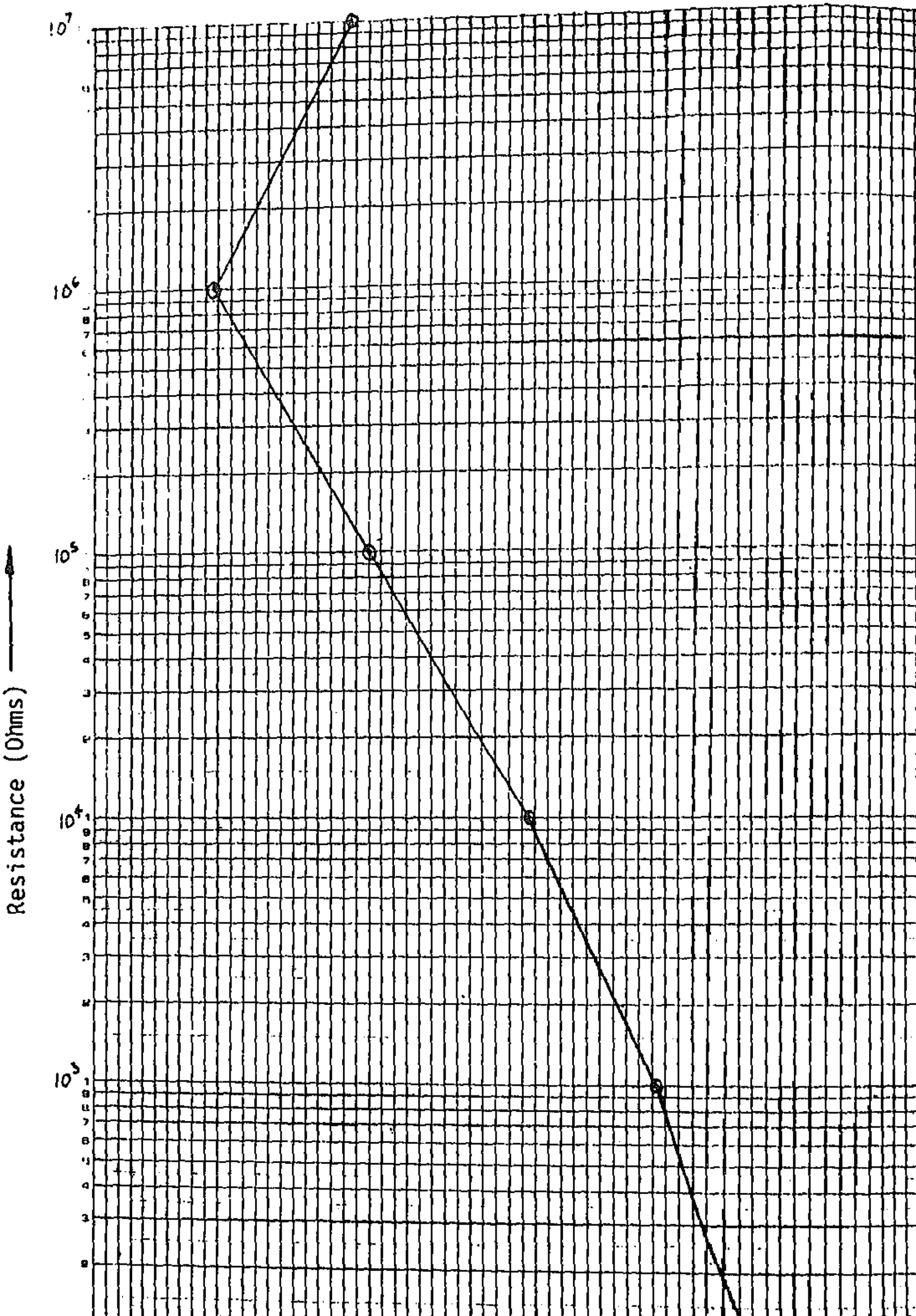

10^7
10^6
10^5
10^4
10^3



Resistance (Ohms)
10^7
10^6
10^5
10^4
10^3



10^7
10^6
10^5
10^4
10^3
10^2



Resistance (Ohms)
10⁷
10⁶
10⁵
10⁴
10³

Section 3

LIME SLURRY INJECTION

GENERAL

High pressure lime slurry was injected in the soil profile surrounding
ses damaged by differential vertical movements. The water-lime slurry mi
injected into the subgrade adjacent to the perimeter of the foundation s
fill fissures and cracks in the subsoil. The injection process increased
sture content of the soil around the critical perimeter area where shrink
occurred. It has been postulated that the soil immediately adjacent to
ssures and cracks filled with slurry would be modified by a reaction betwe
lime and clay and the shrink-swell behavior will be minimized with time.
rther, the lime encompasses clods of soil defined by tension cracks and in
its volume change.

HOUSE LOCATIONS

The two houses where subgrade soils were lime injected are representati
those being investigated under Phase I of this project. One is located a
N.E. 32nd Street in Grand Prairie, Texas, and is founded on soils of th
le Ford geologic formation. The other house is located at 2710 Cary Driv
Mesquite, Texas, and is founded on soils belonging to the Taylor Marl geo
ic formation. Details of the floor plan of each house, injection pattern
trumentation, leveling points, permanent bench mark, injection procedure,
t, soils investigation, and immediate damage reversal have previously bee
en.[1,2]

VERTICAL MOVEMENT

During the injection process vertical movement occurred due to the quan
lime slurry being introduced into the foundation soil at high pressure.
ement was recorded in order to compare the long term vertical movements w
ld be indicative of the effectiveness of the stabilization technique. Al
tour surveys of each floor slab were performed after the injection proecs

.1 830 N. E. 32nd Street, Grand Prairie, Texas

The perimeter foundation soil for this house accepted 9,742 gallons of
rry containing 10.5 tons of lime. The cost of high pressure lime slurry
tion as a remedial measure per lineal foot around the house perimeter was

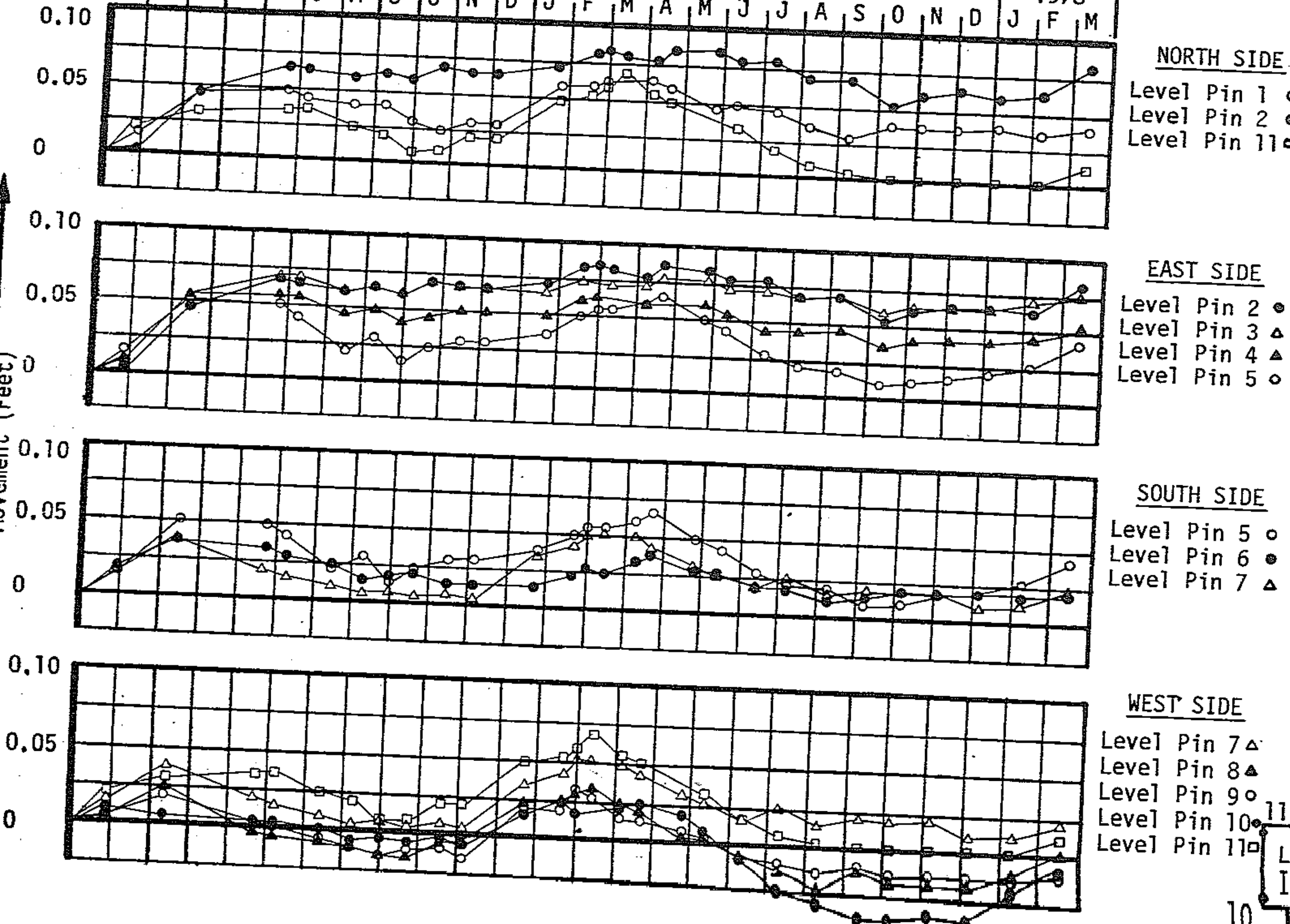


Fig. 11 Vertical Mov

An increase in vertical movement occurred as expected due to the devel
t of double layer water on the clay minerals. This increase will contin
il equilibrium is reached and then fluctuate with climatic cycle. The v
movement increase was related to the amount of moisture available, the
e of desiccation of the foundation soil, and the amount of clay minerals
montmorillonite group present in the soil to the depth of moisture migr

As indicated by Figure 11, the movement will generally lag behind the
nt of the climatic cycle, but can be modified by the effects of trees, s
watering habits or maintenance by the home owner.

Figure 12 indicates the change in elevation or differential movement w
e along each side of the house. Normally, the greatest differential wil
ween corners as two directions will contribute to movement. This, too,
influenced by the factors previously mentioned and also by variation in
perties. Information shown in Figure 12 is also given in Table 3.

.2 2710 Cary Drive, Mesquite, Texas

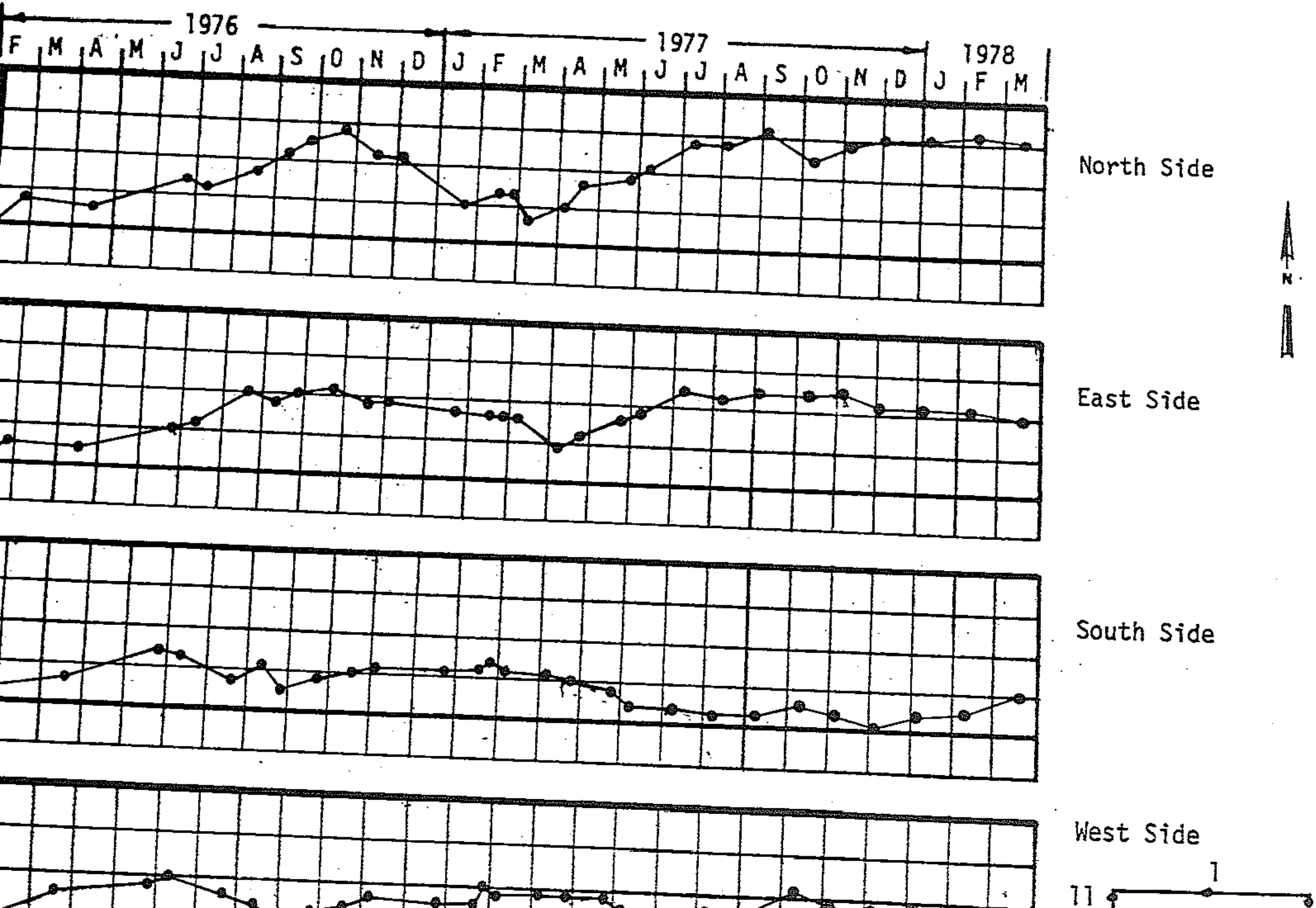
The perimeter foundation soil around this house accepted 16,203 gallon
e slurry containing 20.25 tons of lime. The cost of high pressure lime
rry injection as a remedial stabilization measure around the house perim
$28.27 per lineal foot of the house perimeter.

The vertical movement of the foundation slab appears to be approaching
ble condition as indicated in Figure 13, for the same reasons as given f
agraph 3.3.1. Also indicated is the lag time behind the mid point of a
ic cycle. Figure 14 indicates the maximum differential movement with tim
ng sides of the house, and is also given in tabular form in Table 4.

.3 Comparison of Vertical Movement

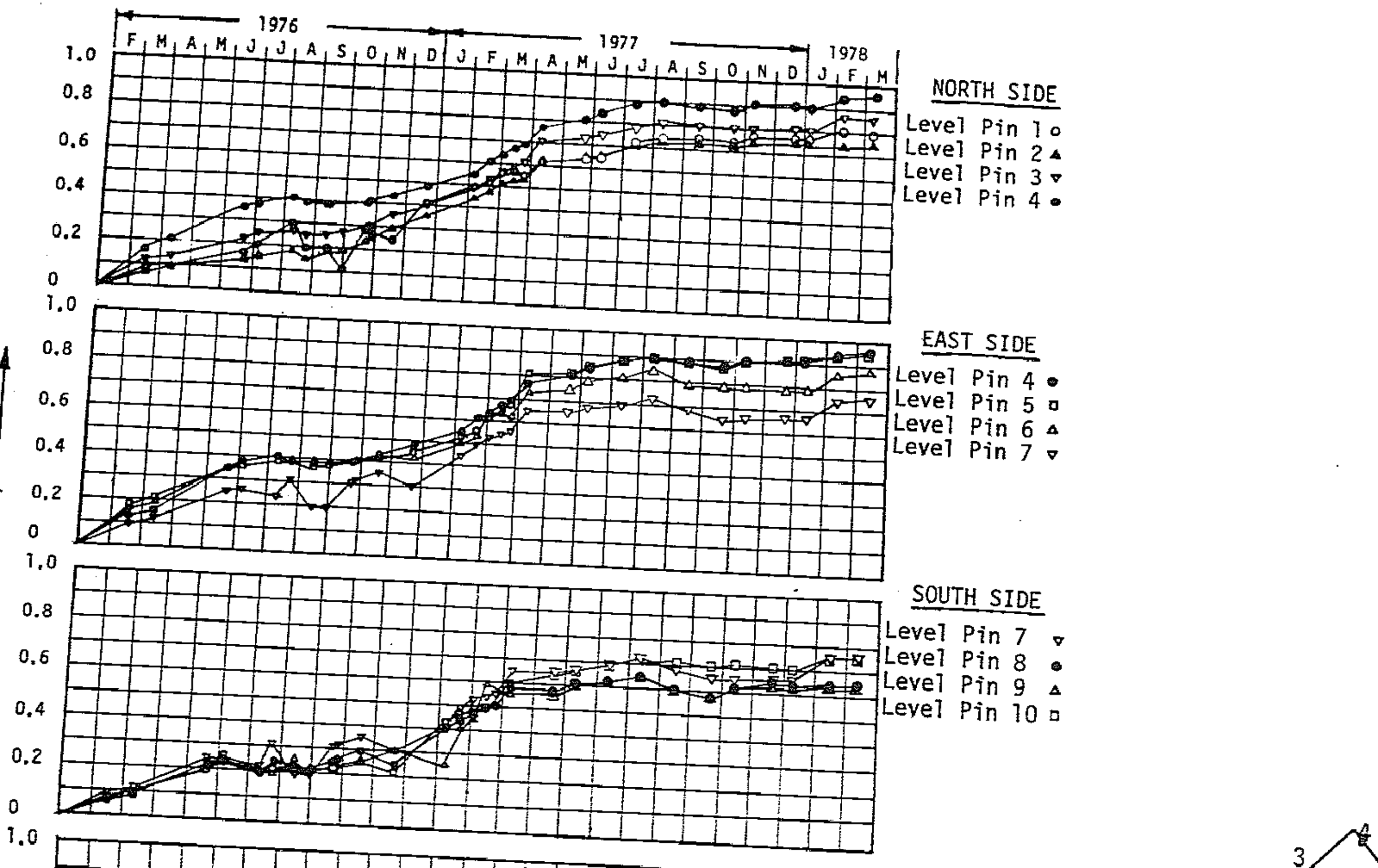
It was evidenced during this project that the Taylor formation was ver
nse and contained significant amount of silts and very fine sand. Planes
kness or desiccation cracks permitted significantly more lime slurry to
jected in the Taylor formation before refusal. The dense condition of th
ghly expansive soils allowed significant quantities of moisture to be acc
the active clay minerals to the depth of moisture migration.

The volume of lime slurry injected into the foundation soils for the
2710 Cary Drive, Mesquite, Texas was 1.66 times the volume required for
use at 830 N.E. 32nd Street, Grand Prairie, Texas, or 16,203 gallons and
742 gallons respectively. The high pressures associated with this techn
50 psi) will open planes of weakness in a fractured soil such as existed
neath the house at 2710 Cary Drive, Mesquite, Texas.



1976
1977
1978
F M A M J J A S O N D J F M A M J J A S O N D J F M
North Side
East Side
South Side
West Side
N
11
1

e	North Side			East Side			South Side			West Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cn
7-76	.018	.216	.549	.011	.132	.335	.006	.072	.183	.016	.192	.4
0-76	.014	.168	.427	.010	.120	.305	.014	.168	.427	.033	.396	1.0
3-76	.030	.360	.914	.021	.252	.640	.030	.360	.914	.039	.468	1.1
9-76	.027	.324	.823	.027	.324	.823	.028	.336	.853	.042	.504	1.2
6-76	.035	.420	1.067	.042	.504	1.280	.015	.180	.457	.032	.384	.9
9-76	.045	.540	1.372	.037	.444	1.128	.023	.276	.701	.029	.348	.8
9-76	.053	.636	1.615	.043	.516	1.311	.010	.120	.305	.022	.264	.6
1-76	.059	.708	1.798	.046	.552	1.402	.019	.228	.579	.027	.324	.8
6-76	.046	.552	1.402	.039	.468	1.189	.021	.252	.640	.029	.348	.8
2-76	.046	.552	1.402	.040	.480	1.219	.024	.288	.732	.036	.432	1.0
1-77	.023	.276	.701	.036	.432	1.097	.023	.276	.701	.033	.396	1.0
3-77	.028	.336	.853	.033	.396	1.006	.027	.324	.823	.034	.408	1.0
3-77	.028	.336	.853	.034	.408	1.036	.026	.312	.792	.041	.492	1.2
1-77	.014	.158	.427	.028	.336	.853	.029	.348	.884	.038	.456	1.1
4-77	.021	.252	.640	.019	.228	.579	.025	.300	.762	.040	.480	1.2
9-77	.035	.420	1.067	.024	.288	.732	.026	.312	.792	.040	.480	1.2
4-77	.037	.444	1.128	.034	.408	1.036	.022	.264	.671	.040	.480	1.2
0-77	.044	.528	1.341	.037	.444	1.128	.016	.192	.488	.032	.384	.9
3-77	.059	.708	1.798	.051	.612	1.554	.009	.108	.274	.028	.336	.8
6-77	.057	.684	1.737	.048	.576	1.463	.008	.096	.244	.035	.420	1.0
3-77	.065	.780	1.981	.051	.612	1.554	.008	.096	.244	.033	.396	1.0
0-77	.052	.624	1.585	.051	.612	1.554	.012	.144	.366	.045	.540	1.3
4-77	.061	.732	1.859	.053	.636	1.615	.009	.108	.274	.036	.432	1.0
1-77	.064	.768	1.951	.047	.564	1.433	.002	.024	.061	.034	.408	1.0
4-78	.064	.768	1.951	.045	.540	1.372	.010	.120	.305	.035	.420	1.0
6-78	.070	.840	2.134	.045	.540	1.372	.011	.132	.335	.023	.276	.7
7-78	.068	.816	2.073	.042	.504	1.280	.020	.240	.610	.035	.420	1.0


1976
1977
1978
F M A M J J A S O N D J F M A M J J A S O N D J F M
1.0
0.8
0.6
0.4
0.2
0
NORTH SIDE
Level Pin 1 ○
Level Pin 2 ▲
Level Pin 3 ▽
Level Pin 4 ●
EAST SIDE
Level Pin 4 ●
Level Pin 5 □
Level Pin 6 △
Level Pin 7 ▽
SOUTH SIDE
Level Pin 7 ▽
Level Pin 8 ●
Level Pin 9 △
Level Pin 10 □
3
4

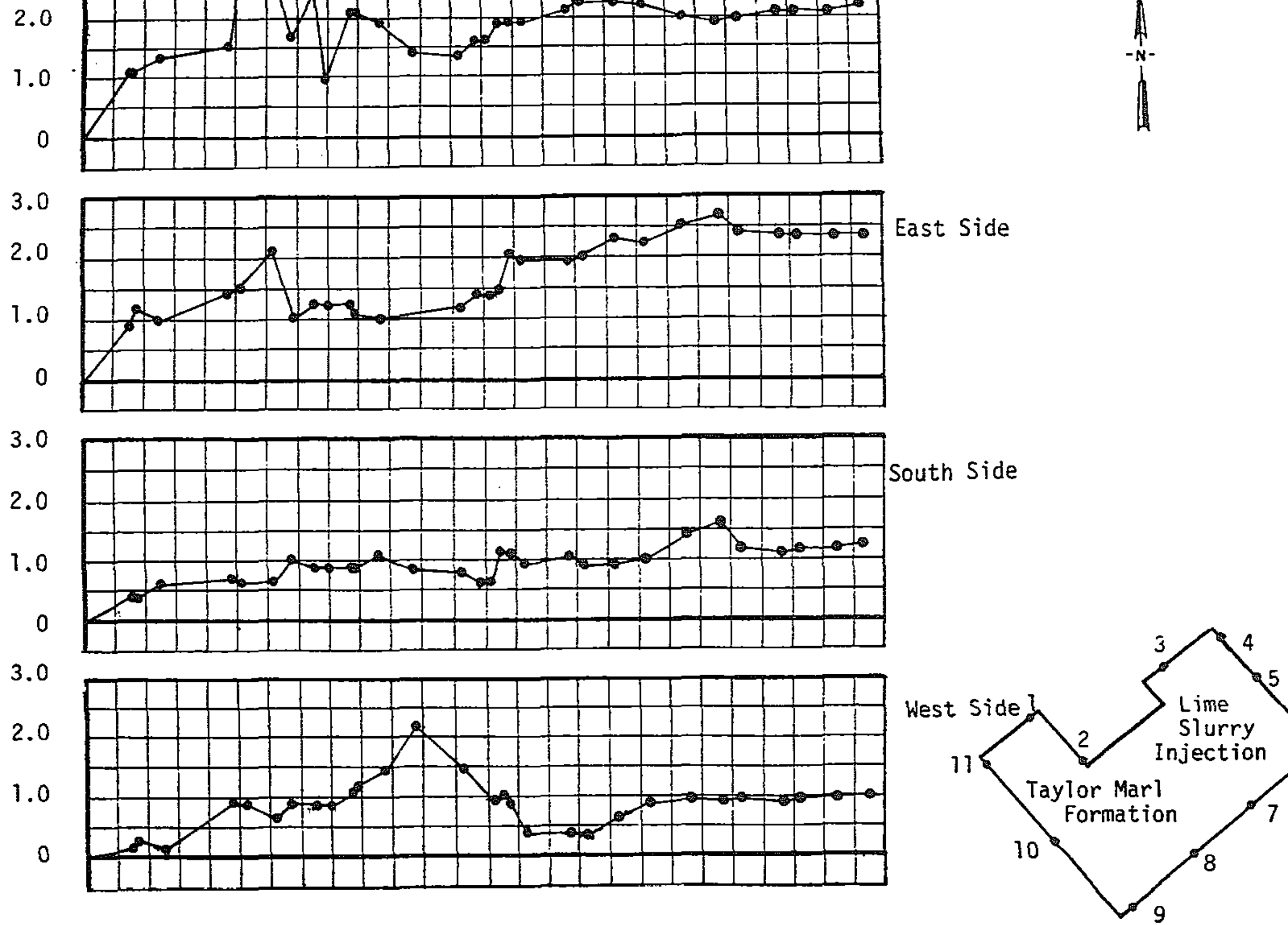


Fig. 14 Differential Elevation on Slab Perimeter

Differential Elevation: Lot

Date	North Side Ft.	North Side In.	North Side Cm.	East Side Ft.	East Side In.	East Side Cm.	South Side Ft.	South Side In.	South Side C
03-16-76	.094	1.128	2.865	.080	.960	2.438	.039	.468	1.
13-18-76	.088	1.056	2.682	.101	1.212	3.078	.037	.444	1.
04-14-76	.115	1.380	3.505	.082	.984	2.499	.046	.552	1.
06-23-76	.126	1.512	3.840	.118	1.416	3.597	.058	.696	1.
07-07-76	.234	2.808	7.132	.126	1.512	3.840	.047	.564	1.
08-11-76	.233	2.796	7.102	.177	2.124	5.395	.052	.624	1.
08-24-76	.133	1.596	4.054	.091	1.092	2.774	.084	1.008	2.
09-15-76	.205	2.460	6.248	.106	1.272	3.231	.070	.840	2.
09-30-76	.081	.972	2.469	.099	1.188	3.018	.070	.840	2.
10-22-76	.179	2.148	5.456	.106	1.272	3.231	.072	.864	2.
10-26-76	.178	2.136	5.425	.094	1.128	2.865	.074	.888	2.
11-18-76	.157	1.884	4.785	.088	1.056	2.682	.091	1.092	2.
12-21-76	.122	1.464	3.719	.184	xx	5.608	.070	.840	2.
02-07-77	.111	1.332	3.383	.104	1.248	3.170	.067	.804	2.
02-21-77	.134	1.608	4.084	.116	1.392	3.536	.044	.528	1.
03-03-77	.135	1.620	4.115	.111	1.332	3.383	.063	.756	1.
03-14-77	.156	1.872	4.755	.131	1.572	3.993	.104	1.248	3.
03-25-76	.166	1.992	5.060	.177	2.124	5.395	.193	1.116	2.
04-11-77	.164	1.968	4.999	.177	2.124	5.395	.083	.996	2.
05-23-77	.182	2.184	5.547	.166	1.992	5.060	.089	1.068	2.
06-09-77	.189	2.268	5.761	.171	2.052	5.212	.079	.948	2.
07-12-77	.183	2.196	5.578	.194	2.328	5.913	.079	.948	2.
08-11-77	.185	2.220	5.639	.187	2.244	5.700	.088	1.050	2.
09-15-77	.168	2.016	5.121	.210	2.500	6.401	.120	1.440	3.
10-21-77	.162	1.944	4.938	.227	2.724	6.919	.129	1.548	3.
11-11-77	.166	1.992	5.060	.206	2.472	6.279	.103	1.236	3.
12-20-77	.177	2.124	5.395	.198	2.376	6.035	.093	1.116	2
01-05-78	.173	2.100	5.334	.198	2.376	6.035	.098	1.176	2
02-13-78	.176	2.112	5.364	.199	2.388	6.066	.099	1.188	3
03-10-78	.184	2.208	5.608	.201	2.412	6.126	.102	1.224	3

A comparison of Figure 11 and 13, pages 22 and 26, indicates the magnitu vertical movement associated with this stabilization technique. A maximu tical movement of approximately 11 inches has occurred for the house at 2 y Drive, Mesquite, Texas, and a maximum vertical movement approximating o h occurred some 10 months earlier at the test house at 830 N.E. 32nd Stre nd Prairie, Texas.

It was also seen from the vertical movements given in Figure 11 page 25, t climatic effects were having an influence on the stability of the found ls. These movements appeared to be dampening out with time, however, the t the condition exists would defeat the objective of the stabilization pr matic effects are not as apparent in Figure 13, page 29, however, this wa ributed to the scale of the figure. It can be seen from Figure 14, page 3 magnitude of differential movements occurring over a short period of tim very undesirable.

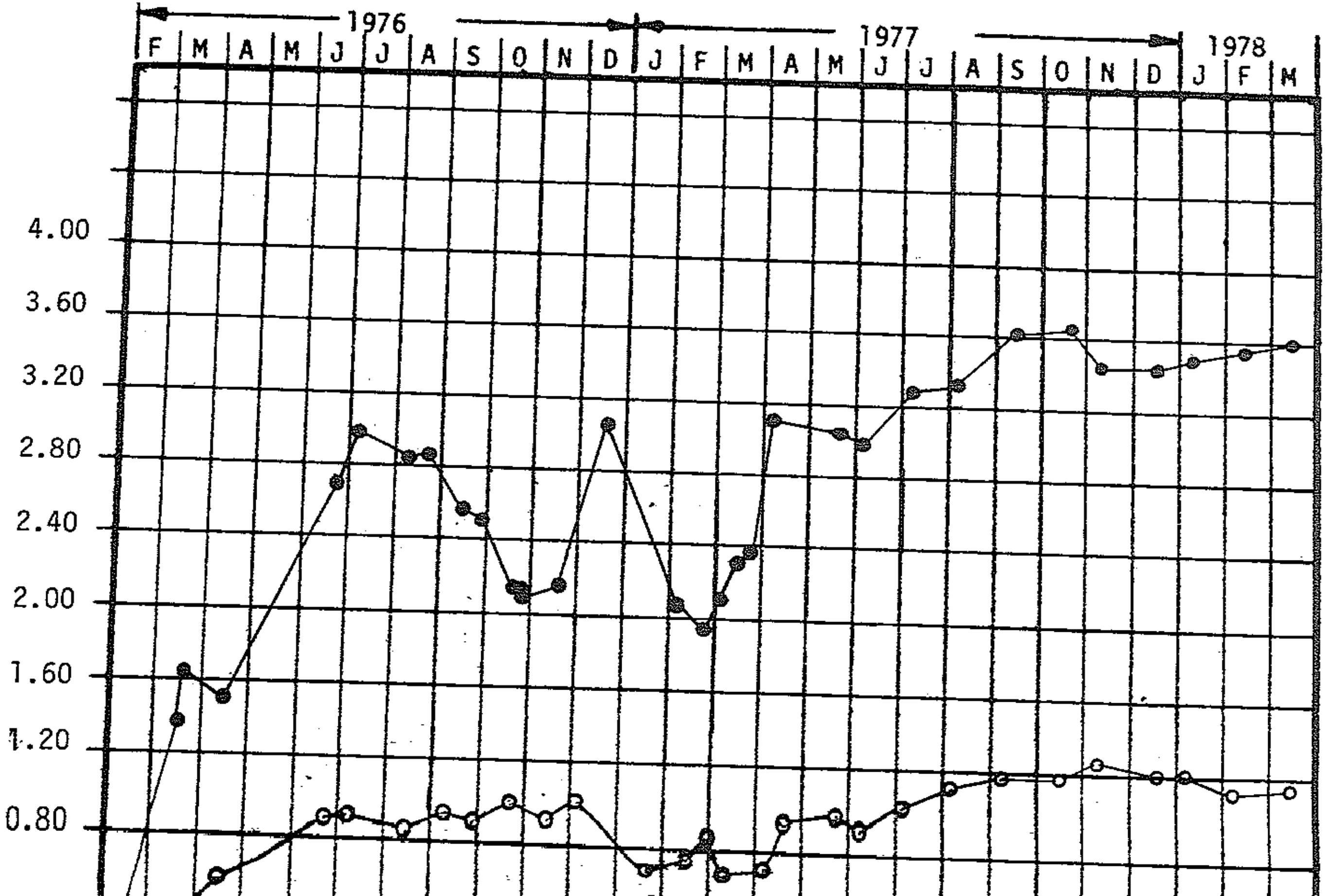
Figure 15, and Tables 5 and 6, show a comparison of lime slurry pressu ection as a soil stabilization technique. Values shown are absolute valu give an indication of technique effectiveness as well as activity of eac mation for the period of time of this study. As each curve becomes asymp a horizontal plane, a condition of stability was considered approaching. seen the differential movements associated with a stability condition co be considered acceptable.

SOIL-MOISTURE-TEMPERATURE CHARACTERISTICS

The placement of moisture-temperature cells at specified depths in the ion soil have previously been discussed[1,2]. It is reiterated, that the ing for each instrument string could not be placed closer to the perimete de beam than one foot due to equipment limitations. Consequently, stabil g actions were approximately 18-24 inches outside the perimeter beam. Th izontal area completely around the perimeter of the house was subjected t matic conditions to some degree.

Moisture data is presented by plotting it at the same depths on all fou es of the test houses. Thus, there will be four curves at each depth wit foundation soil (except for the houses where lime slurry pressure inject studied as a stabilization technique). Here five curves are presented w fifth curve indicating comparative moisture contents of the soil at equi t depths for instruments established in a soil boring outside the injecte a.

Temperature data was analyzed in two ways: (1) temperature vs. time, average temperature for parallel sides vs. time. Cyclic variation is de plots of temperature vs. time. These plots have been developed for the d instrument installation. Temperature data is averaged for the borings al allel sides of the structure. For each house and each depth, two curves


1976
1977
1978
F M A M J J A S O N D J F M A M J J A S O N D J F M
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80

Date	Movement		
	Feet	Inches	Cm.
Feb. 27, 1976	.018	.216	.549
Apr. 14, 1976	.049	.588	1.494
June 23, 1976	.073	.876	2.225
July 9, 1976	.074	.888	2.256
Aug. 16, 1976	.069	.828	2.103
Sep. 9, 1976	.076	.912	2.316
Sep. 29, 1976	.075	.900	2.286
Oct. 21, 1976	.086	1.032	2.621
Nov. 16, 1976	.075	.900	2.286
Dec. 2, 1976	.084	1.008	2.560
Jan. 21, 1977	.059	.708	1.798
Feb. 18, 1977	.062	.744	1.890
Feb. 28, 1977	.069	.828	2.103
Mar. 11, 1977	.057	.684	1.737
Apr. 4, 1977	.061	.732	1.859
Apr. 19, 1977	.075	.900	2.286
May 24, 1977	.080	.960	2.438
June 10, 1977	.076	.912	2.316
July 8, 1977	.087	1.044	2.652
Aug. 5, 1977	.094	1.128	2.865
Sep. 8, 1977	.099	1.188	3.018
Oct. 10, 1977	.095	1.140	2.896
Nov. 4, 1977	.102	1.224	3.109
Dec. 1, 1977	.098	1.176	2.987
Jan. 4, 1978	.100	1.200	3.048
Feb. 6, 1978	.093	1.116	2.835
Mar. 17, 1978	.095	1.140	2.896

Date	Movement		
	Feet	Inches	Cm.
Mar. 16, 1976	.119	1.428	3.627
Mar. 18, 1976	.138	1.656	4.206
Apr. 14, 1976	.128	1.536	3.901
June 23, 1976	.226	2.712	6.888
July 7, 1976	.244	2.928	7.437
Aug. 11, 1976	.235	2.820	7.163
Aug. 24, 1976	.236	2.832	7.193
Sep. 15, 1976	.215	2.580	6.553
Sep. 30, 1976	.204	2.448	6.218
Oct. 22, 1976	.179	2.148	5.456
Oct. 26, 1976	.178	2.136	5.425
Nov. 18, 1976	.179	2.148	5.456
Dec. 21, 1976	.254	3.048	7.742
Feb. 7, 1977	.171	2.052	5.212
Feb. 21, 1977	.160	1.920	4.877
Mar. 3, 1977	.174	2.088	5.304
Mar. 14, 1977	.192	2.304	5.852
Mar. 25, 1977	.198	2.376	6.035
Apr. 11, 1977	.260	3.120	7.925
May 23, 1977	.255	3.060	7.772
June 9, 1977	.250	3.000	7.620
July 12, 1977	.273	3.276	8.321
Aug. 11, 1977	.275	3.300	8.382
Sep. 15, 1977	.301	3.612	9.174
Oct. 21, 1977	.302	3.624	9.205
Nov. 11, 1977	.287	3.444	8.748
Dec. 20, 1977	.391	3.492	8.870
Jan. 5, 1978	.293	3.516	8.931
Feb. 13, 1978	.298	3.576	[illegible]

Averaging of temperature data was done to yield a less cumbersome grap
ever, it obscures the individual temperature variations that are present
show these, calculations of means and standard deviations of temperature
sented in tables for each boring and at each depth. The standard deviat
icates the amount of variation contained in the data. A small standard
tion indicates data which is clustered around the mean value, and a larg
ndard deviation indicates data which has large fluctuations above and bel
mean. The standard deviations indicate the relative amounts of variatio
time. These tables indicate the temperature is not uniform around the
imeter.

.1 830 N.E. 32nd Street, Grand Prairie, Texas

Data acquisition for variation in soil moisture content with time, as
Figure 16, began upon completion of the high pressure lime slurry pressu
ection. It is readily apparent that the soil moisture content immediatel
er the injection process, and with time, has a wide variation. This vari
indicative of the slurry migrating away from the desired area of treatmen
the stabilization technique was effective, the soil moisture contents at
ths of interest should fall within a very narrow band width and remain re
ely horizontal with time. It can be seen that climatic conditions are in
encing the soil moisture content at all depths of interest. In addition,
t systems from trees and other vegetation would contribute to an apparent
matic effect at near surface elevations. The curve indicating soil moist
tent at all depths of interest outside of the treatment area is not signi
tly different than the four curves within the treatment area. This is an
ication that moisture migration has not been appreciably inhibited and wa
ctuating with climatic conditions.

The variation of the soil temperature as given in Figure 17 shows the c
eristic sine wave with changes associated with climate. Temperature data
and should not have any or significant lag time as would be the case for
sture. At the depths of interest, the amplitude of the characteristic wa
reases with the depth of soil cover. The temperature means and standard
tions are given in Table 7.

Increasing the soil moisture content to a value of 2-3 percent above th
stic Limit, which is desirable, was not successful utilizing this stabili
n technique. It can be seen that for each depth of interest, the moistur
tent should have approached and maintained a value of approximately 24-25
cent for an average Plastic Limit of approximately 22 percent. Instead t
sture content never exceeded 20 percent and fluctuated widely with the se

.2 2710 Cary Drive, Mesquite, Texas

appropriate for this test house.

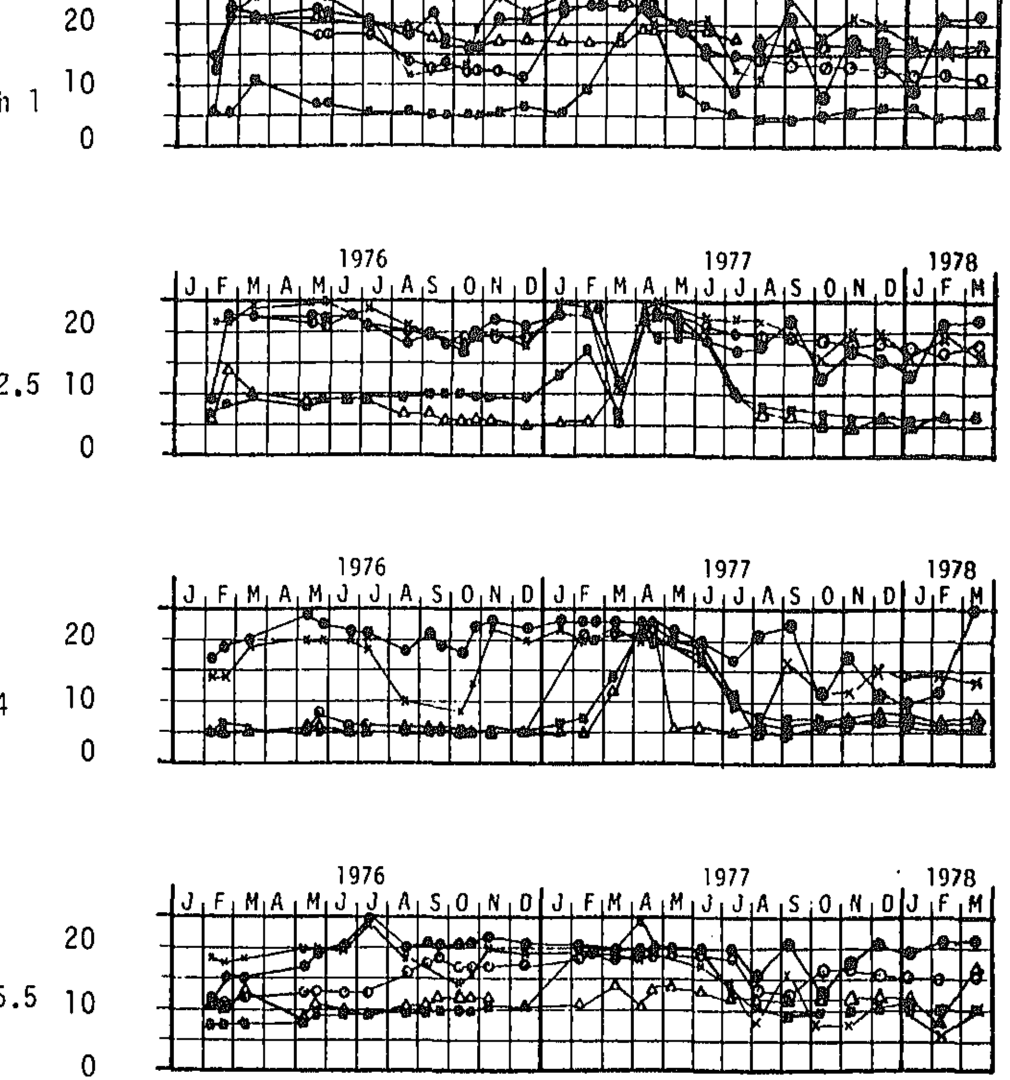
The average Plastic Limit within the depths of interest was ap
36%. This would establish a desirable soil moisture content of 38-
can be seen, initially, moisture contents approached this value but
be maintained by this stabilization technique.

The variation of the soil temperature with time and depth is g
Figure 19. This figure illustrates the characteristic sine wave w
tude decreases with depth. Temperature means and standard deviatio
given in Table 8, page 37.

3.4.3 Comparison of Moisture-Temperature Characteristics

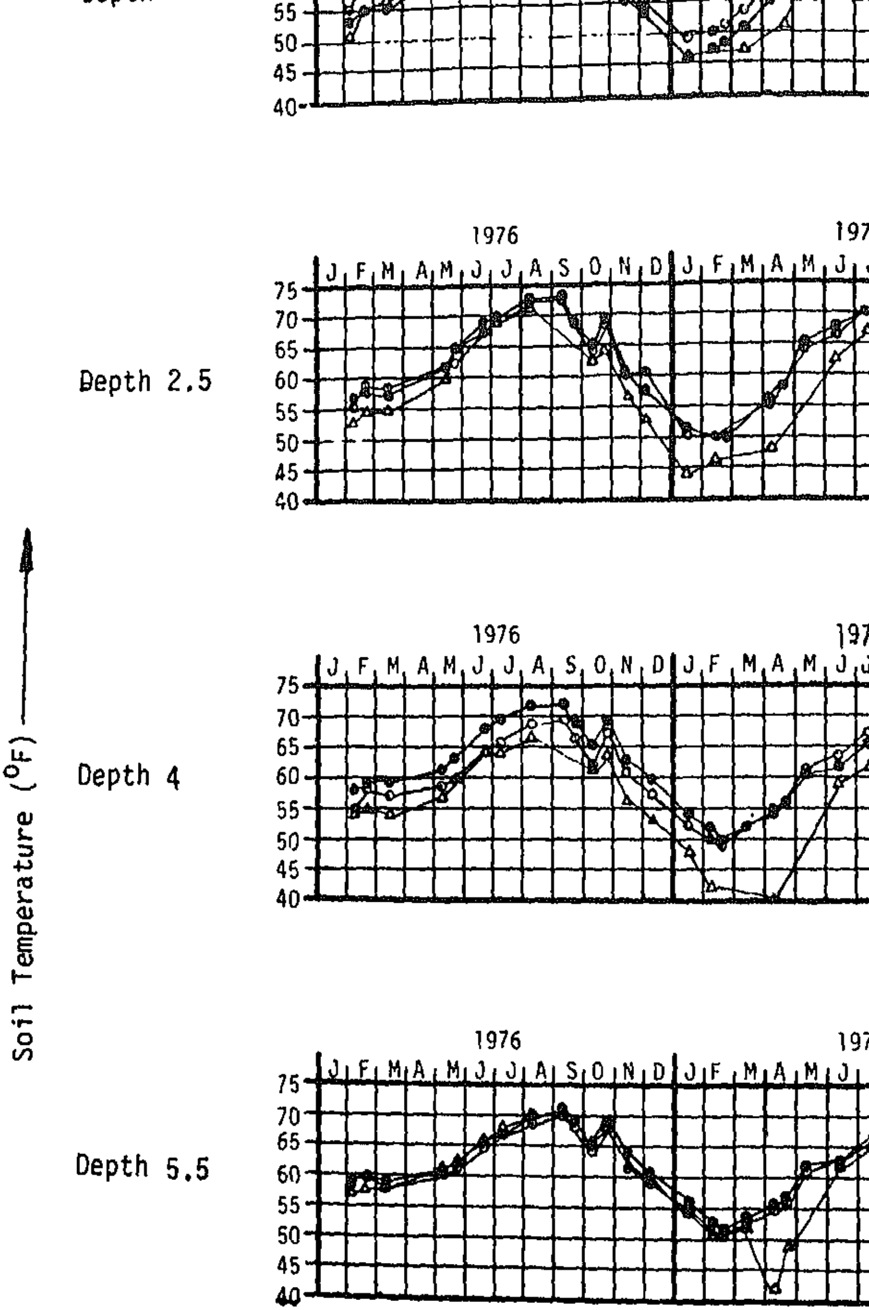
The variation of soil moisture content with time for these two
different geologic formations is as dramatic as the variation in ve
ments. From the soils investigation for these two houses, the soil
perties such as natural water content, Plastic Limit, and Liquid Li
significantly higher in the Taylor formation, or the house located
Drive, Mesquite, Texas. Further, the natural water content of the
depth for the Taylor formation was significantly lower than the Pla
of the soil. Within depths of interest in this investigation, the
of soil moisture variation was as much as 11% below the Plastic Lim
Taylor formation, whereas in the Eagle Ford formation 5% below the
Limit appeared to be maximum. In addition, the percentage of montm
clay minerals determined by x-ray Defraction Analysis was much grea
Taylor formation than in the Eagle Ford formation. For depths of 7
the soil surface, the increase (in what) was as much as 45 percent
elevations and 20 percent at the 7 foot depth. The lime slurry lar
inserted to this depth; however, the extent of the moisture migrati
and laterally along fissures and planes of weakness was unknown, as
would be a function of the degree of desiccation and past geologic
However, it is believed that moisture migration was wide spread for
pressures of 150 psi, and both, the vertical movements and moisture
support this premise.

The high specific surface area of montmorillonite clay minera
meters per gram), along with the large volume of water introduced
profile of the house located on the Taylor formation versus the hou
the Eagle Ford formation indicates the subsoil under the house at
Mesquite, Texas, was capable of retaining more moisture. Reference
page 30, which compares the maximum perimeter differential movemen
house where the subsoil was treated by lime slurry pressure injecti
figure indicates the significant difference in activity of the subs
the houses on the Taylor and Eagle Ford formations. Similar indica
given by comparing Figures 11 and 13, pages 22 and 26, which show



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring
x Instruments Outside of Lime Treatment Area
* Refers to Depth Below Perimeter Grade Beam

Fig. 16 Soil Moisture Content - Lime Slurry Injection
830 N.E. 32nd Street, Grand Prairie, Texas



-Key-

- ○ North and South Side Average
- ● East and West Side Average
- △ Instrument Outside of Lime T

*Depth

URE MEANS AND STANDARD DEVIATION

. 32nd Street, Grand Prairie, TX

Lime Injection

n	*Depth (ft) 1	2.5	4	5.5
	62.00 9.58	61.82 7.54	58.98 6.92	60.45 6.40
	58.58 8.70	61.47. 8.00	60.28 7.50	61.93 6.24
	63.89 7.59	63.11 6.10	61.45 5.45	60.97 5.08
	63.47 9.14	64.55 6.83	63.48 5.90	61.71 5.13
e nt	59.68 12.38	58.63 8.43	56.63 7.84	59.28 7.53

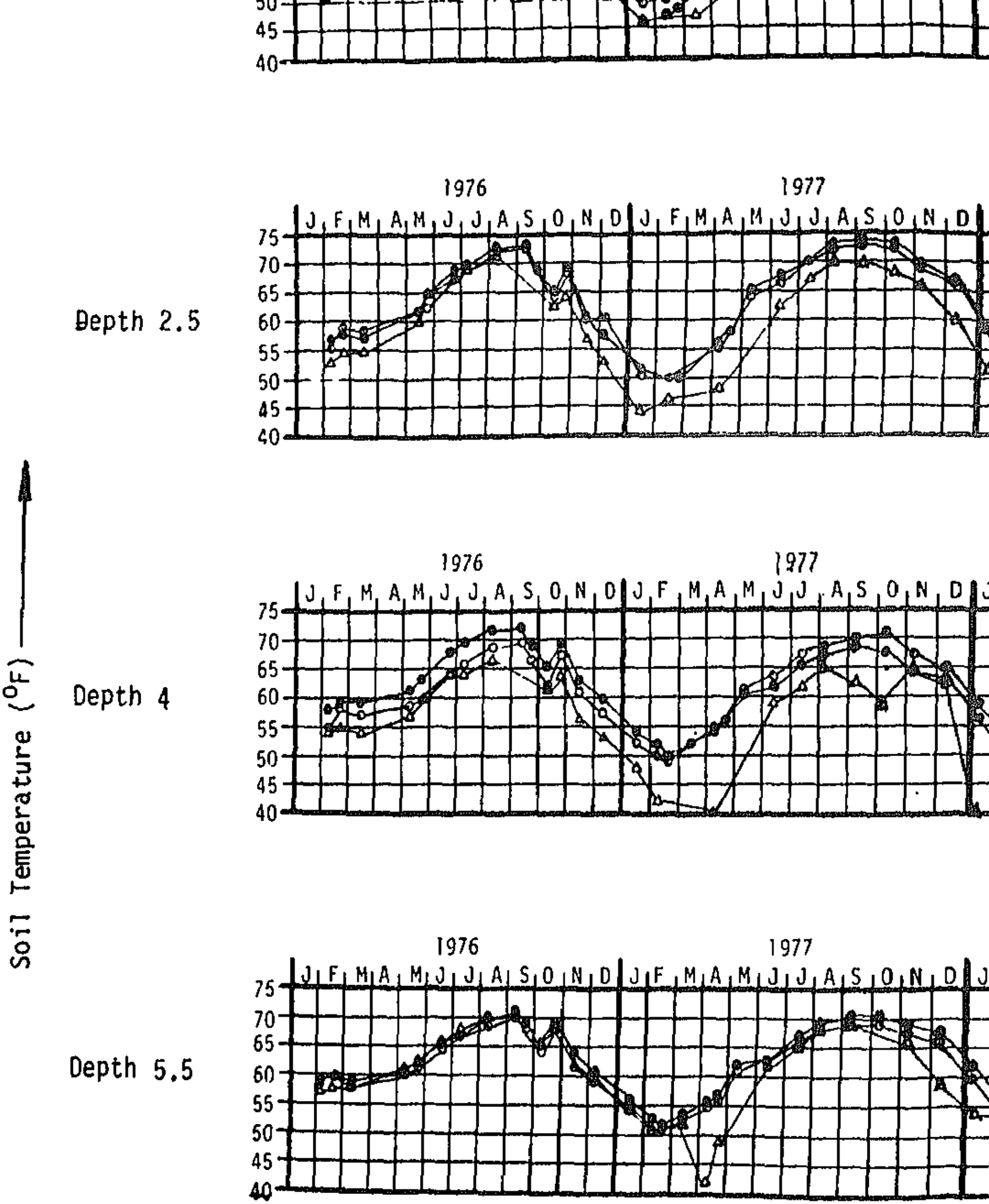
pth refers to feet below grade beam.

TEMPERATURE MEANS AND STANDARD DEVIATIO

2710 Cary Drive, Mesquite, TX

Lime Injection

Cell Location	*Depth (ft) 1	2.5	4
North	63.92 9.80	61.61 8.94	60.18 7.71
East	63.93 8.73	61.05 7.42	62.30 6.22
South	64.95 7.62	61.83 5.55	61.32 6.01
West	62.93 5.17	61.55 6.90	60.77 6.09
Outside Treatment Area	63.94 7.38	61.64 6.85	56.70 5.82



-Key-

- o North and South Side Average
- ● East and West Side Average
- △ Instrument Outside of Lime Treatment Area

*Depths refer to feet below grade beam.

N.E. 32nd Street, Grand Prairie, TX

Lime Injection

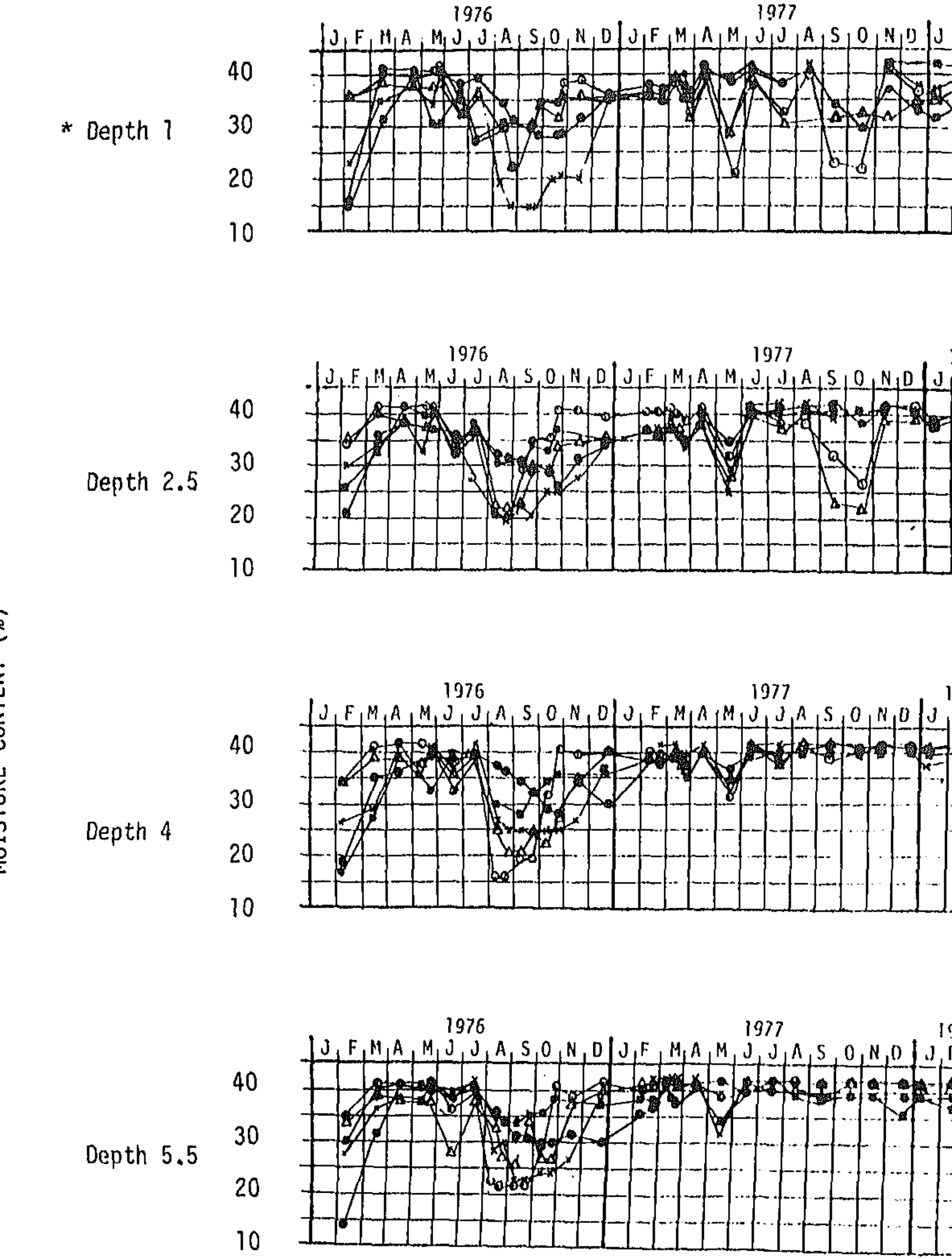
ell ation	*Depth (ft) 1	2.5	4	5.5
rth	62.00 9.58	61.82 7.54	58.98 6.92	60.45 6.40
st	58.58 8.70	61.47 8.00	60.28 7.50	61.93 6.24
uth	63.89 7.59	63.11 6.10	61.45 5.45	60.97 5.08
st	63.47 9.14	64.55 6.83	63.48 5.90	61.71 5.13
utside eatment Area	59.68 12.38	58.63 8.43	56.63 7.84	59.28 7.53

2710 Cary Drive, Mesquite, T

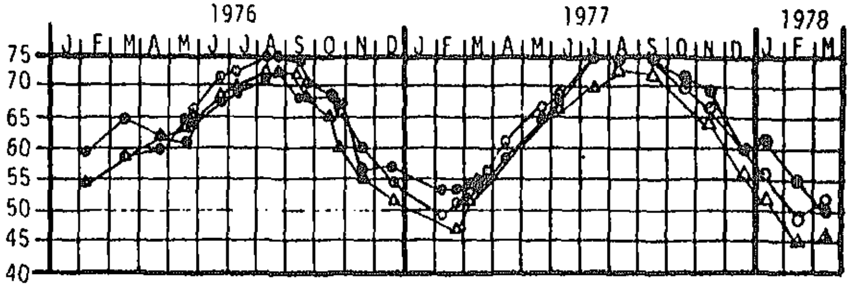
Lime Injection

Cell Location	*Depth (ft) 1	2.5	4
North	63.92 9.80	61.61 8.94	60.1 7.7
East	63.93 8.73	61.05 7.42	62.3 6.2
South	64.95 7.62	61.83 5.55	61.3 6.0
West	62.93 5.17	61.55 6.90	60.7 6.0
Outside Treatment Area	63.94 7.38	61.64 6.85	56.7 5.8

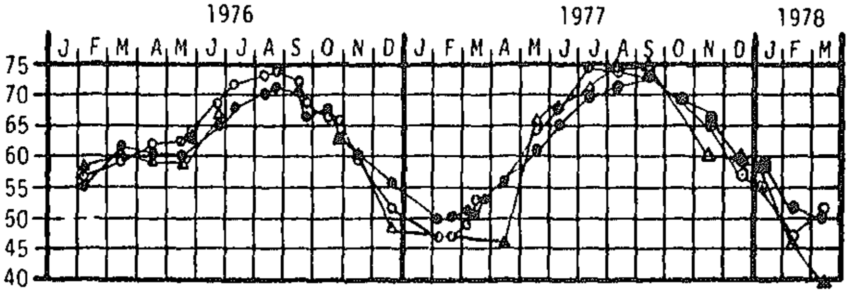
*Depth refers to feet below grade beam.


MOISTURE CONTENT (%)
* Depth 1
Depth 2.5
Depth 4
Depth 5.5
1976
1977
J F M A M J J A S O N D J F M A M J J A S O N D J
40
30
20
10

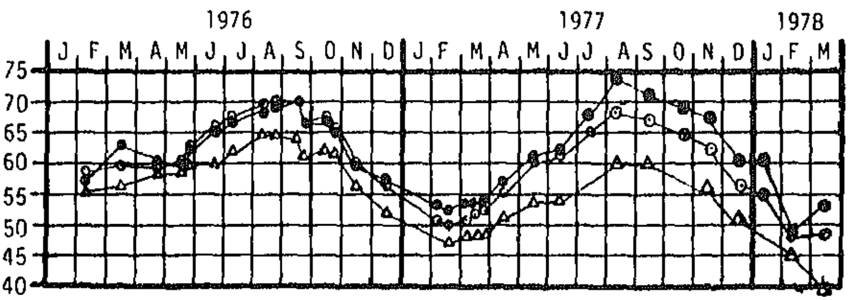
h 1



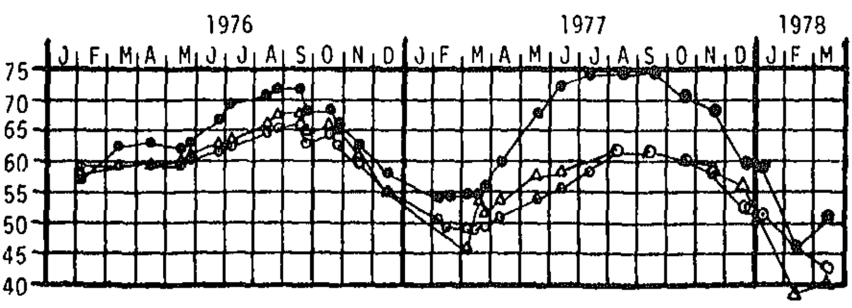
th 2.5



th 4



th 5.5



e foundation soil beneath the house at ... in ..., ...
xas, appeared to be approaching a stable condition within several months,
e foundation soils beneath the house at 2710 Cary Drive, Mesquite, Texas,
ntinued to swell appreciably for over 18 months. This condition may cont
a reduced rate until the clay minerals have satisfied their double layer
ter requirement for equilibrium.

The comparison of Figures 17 and 19, pages 36 and 39, for soil temper
riation indicate excellent agreement. Consequently, it would appear that
riation of soil temperature with depth is essentially a function of clima
riation, and not a significant variable for magnitudes of vertical moveme
tained. Both referenced figures give an indication of the insulating pro
soil. This is further justified by the values of temperature means and
andard deviations with depth for both houses given in Tables 7 and 8,
. The correlation of temperature data is excellent and supports the acc
other data values.

5 EVALUATION OF LIME SLURRY PRESSURE INJECTION FOR STABILIZATION

The use of lime to inhibit shrink and swell in clay has long been esta
shed and used with excellent results. This has usually been in major con
ruction where intimate blending of lime slurry and clay can be achieved a
e optimum water content of the mixture maintained. Excellent results hav
en obtained using the injection process in stabilizing railroad sub-grade
at have been restored to desirable configurations. The injection process
s also been used successfully in stabilizing large areas of soil to a 7
ot depth, with the surface soil being blended with the returned slurry and
mpacted to an optimum density. In all these instances, sufficient space
ually available to accommodate large construction equipment required to ac
e desired results. Consequently, long term modifications to clays may occ
d shrink-swell characteristics will be altered.

The use of established lime slurry injection procedures to stabilize th
undation soils around house perimeters to preclude excessive differential
vements would appear to have some limitations. The cost associated with a
abilization technique is of significant interest to the home owner, and us
lime slurry pressure injection is the most costly of all methods used in
udy. A considerable investment in specialized equipment is required for l
urry pressure injection and this necessitates the use of a contractor who
ecializes in this type of work. Essentially, the same type of equipment i
quired for injecting around a house perimeter as would be required along
ther a railroad right of way or a large expanse of soil such as a parking
an apartment complex. While equipment type may be the same, more special
on is required for the subsoil around a house perimeter.

The cost of lime slurry pressure injection is a function of the size of
ea to be treated and the amount of time required to accomplish the job. F
stressed house, space limitations due to lot size and adjacent buildings

o the foundation soil by a vibrating device at the top. It is extremely ficult to maintain the alignment of the lance in the soil with vibrating ipment at the top plus a hose connection to the slurry pump which is injec at approximately 150 psi. Consequently, the injection hole tends to beco arged permitting return of the slurry up around the lance, and this may or not be before an adequate amount of lime slurry has been injected into th soil. The necessity of using hand held lances increases the labor require e requirement, and cost.

In using lime slurry pressure injection around a building perimeter the unt of lime slurry remaining within or close to the narrow injected area i eterminate. The lime slurry is free to migrate away from the two vertical nes defining the injected area or barrier. If the clay is desiccated or nly fractured, the lime slurry may migrate laterally great distances, both eath and away from a building. Not only will the slurry migrate along ctures and tension cracks, but the high pumping pressure (150 psi) used in e slurry pressure injection will permit planes of weakness in the soil to n causing other avenues of lime slurry travel. Consequently, there is a stion and doubt as to whether an adequate barrier has been or can be estab hed which will inhibit moisture migration and restrict the shrinking and lling of the foundation soil. This is demonstrated by Figures 16 and 18, es 38 and 41. It can readily be seen that variations in moisture content a n depth around the perimeter of both test houses is varying with the hot a and cool and wet seasons of the year, with characteristic lag time.

The use of lime slurry pressure injection around a building perimeter ha pletely different parameters than using the technique to stabilize a large l mass. For a large surface area, lime slurry migration into areas previo ected is inhibited by buildup of pore pressure within the areas previously ected. The end result is a large soil mass, defined by four vertical plan ch would be subjected to lateral lime slurry migration. However, the inte the soil mass will have more uniform distribution of lime slurry than coul expected in injecting a comparatively narrow strip around a building.

MOISTURE MIGRATION BARRIERS

GENERAL

Six houses damaged by differential soil movements were treated by utili
ous type barriers to mitigate or minimize moisture migration. In additi
foundation soil moisture was increased 2-3 percent above the Plastic Lim
types of barriers installed included a gravel capillary barrier, a rubbe
ry barrier, and a lean concrete barrier. Each type of barrier was insta
nd a distressed house in the soil of each geologic formation being consi

It was apparent from the beginning, that a desirable vertical barrier w
ery difficult to install with conventional excavation or trenching equip
ently being utilized in the construction and home building industry. Id
equipment would be small and maneuverable to cope with directional chang
he house perimeter as well as avoiding any encroachment to adjoining pro
s. The equipment must also be designed to be structurally strong and po
enough to excavate a vertical trench no less than five feet deep and hav
bsolute minimum width, without losing directional stability. These requ
s are not as stringent for new construction, but become very important fo
of remedial techniques in existing subdivisions. Equipment available wa
limited to a nominal four inch trench width for an excavation depth of
feet, and the nominal four inch width rapidly becomes a six to eight inc
n when excavating in desiccated materials. This will greatly increase th
of the vertical barrier.

It is of interest to note that since the beginning of this research proj
of the major manufacturers of excavation and trenching equipment presentl
g utilized in the construction and home building industry has reengineere
model to date that will allow the excavating arm to be moved to either si
he drive wheels. This capability will permit trenching immediately adjac
house perimeter grade beam plus eliminating problems associated with
ctional changes of the house exterior. Further, less trenching would be
ired, less barrier material would be used and costs associated with a ver
barrier would be reduced accordingly. Of equal significance, would be th
ination of an area approximately two feet wide multiplied by the length
ouse perimeter which would be subjected to greater climatic effects than
barrier was immediately adjacent to the house perimeter beam. The elimin
of this area would also contribute to lowering costs by eliminating exca
on of the horizontal area and sloping the barrier up to the bottom of the
meter beam and then restoring the ground surface.

.2 GRANULAR CAPILLARY BARRIERS*

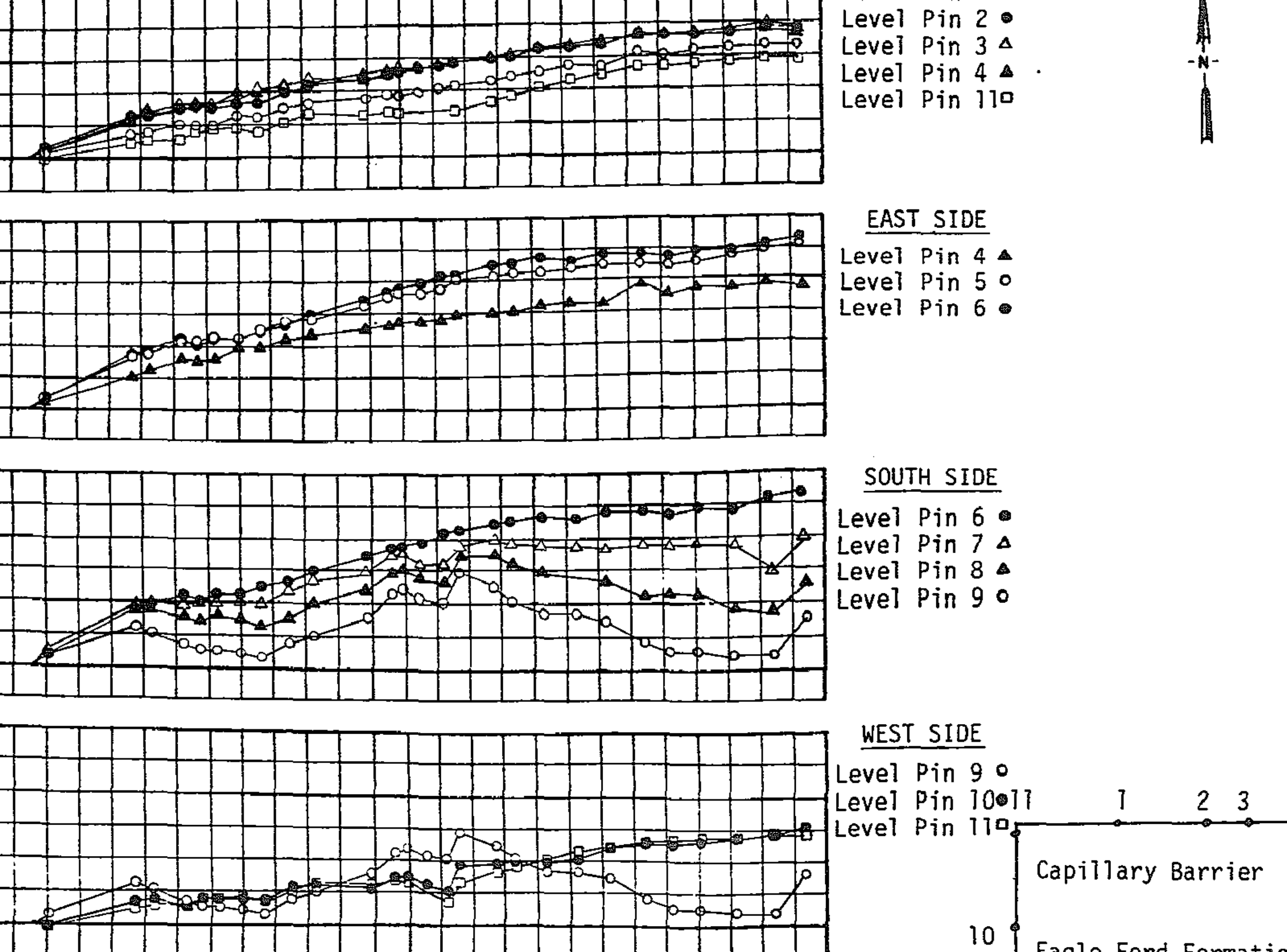
The first house around which a granular capillary barrier was placed ocated at 1642 Cedar Keys Drive in Lewisville, Texas, and is founded on s f the Eagle Ford geologic unit. The other is located at 9909 Bluffcreek rive in Dallas, Texas, and is located in the area underlain by the Taylor arl geologic formation. Details of the floor plan, leveling points, perm ench mark, soils investigation, costs and increasing foundation soil mois ave previously been given. Contour surveys of each floor slab prior and ubsequent to corrective actions have been reported.[1,2]

.2.1 Vertical Movement - 1642 Cedar Keys Drive, Lewisville, Texas

Data acquisition of vertical movements around the foundation perimete nitiated after the capillary barrier was in place and the foundation soil oisture content increased to 2-3 percent above the Plastic Limit of the s he soil moisture content had to be determined by test as any computed qua ity of water to be added to the soil would not be an accurate indication. his was because free water could migrate across the capillary barrier and his did occur.

The floor slab for the house at 1642 Cedar Keys Drive, Lewisville, Te ad a "cupped" shape. The perimeter edges were higher than the interior p ater was added to the foundation soil from the interior of the house usin uger borings at selected points. Damage reversal was observed in this ho ithin a short time after the soil moisture content was increased and an a ional contour survey of differential slab elevations was performed.

Figure 20 shows the vertical movements along each side of the test ho ith time. The performance period is for two years or the effects of four easonal cycles. It can be seen that the southeast corner of the house is igh point and the southwest corner the low point around the perimeter. I his area, it would be anticipated that the northeast corner would be the igh point; however, the anisotropic properties of the subsoil, the effect f vegetation, and the degree of maintenance by the homeowner could accoun or this elevation change which approximated 0.72 inches. In analyzing the ertical movements, the magnitude of elevation change along the south side f the house is considered important. The overall change in elevation fro he southwest corner to the southeast corner approximates 0.23 foot or appr ately 2.76 inches. While this is a significant change in elevation, it c e seen that the change between leveling points is very uniform, which is esirable. Of equal importance is that the effects of seasonal or climati hanges are to a great extent dampened out. This is evident on the north a ast sides of the house as indicated in Figure 20, and also in Figure 21 w hows the amount of differential elevation with time along each side of the ouse. Table 9 provides this data in tabular form.


Level Pin 2
Level Pin 3
Level Pin 4
Level Pin 11
EAST SIDE
Level Pin 4
Level Pin 5
Level Pin 6
SOUTH SIDE
Level Pin 6
Level Pin 7
Level Pin 8
Level Pin 9
WEST SIDE
Level Pin 9
Level Pin 10
Level Pin 11
-N-
11
1
2
3
10
Capillary Barrier

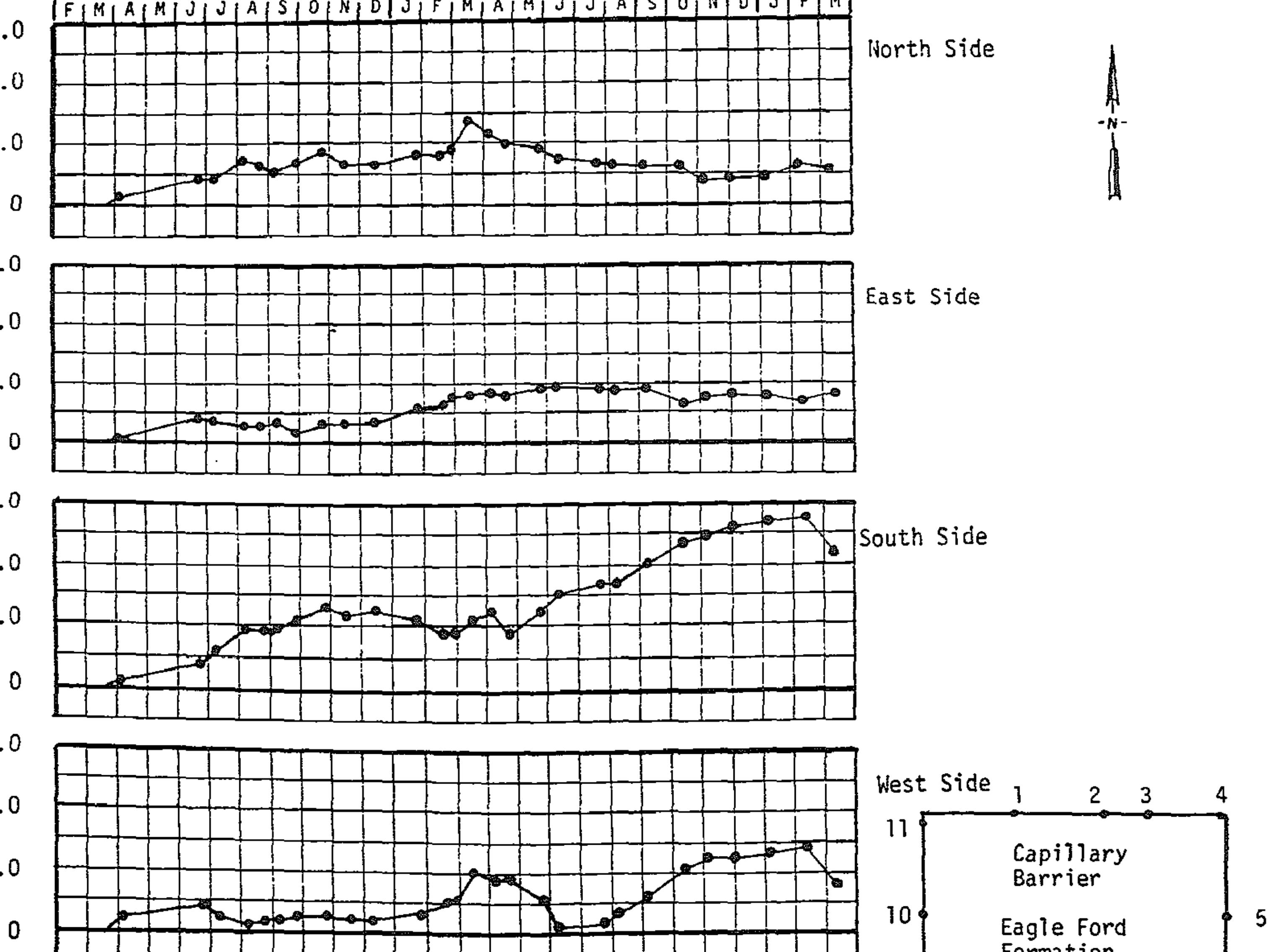
ertical Movement - 9909 Bluffcreek, Dallas, Texas

cquisition for the test house commenced after installation of the arrier and increase of moisture in the foundation subsoil. Again, amount of water could not be considered factual, due to free water cross the barrier, and the soil moisture content was determined by

oor slab for the house at 9909 Bluffcreek, Dallas, Texas, had a pe, or the edges of the slab were lower than the slab interior. dded to the subsoil from the exterior of the house through the arrier and beneath the perimeter grade beam. While no immediate age reversal was noted, an additional contour survey of differen- levations was performed.

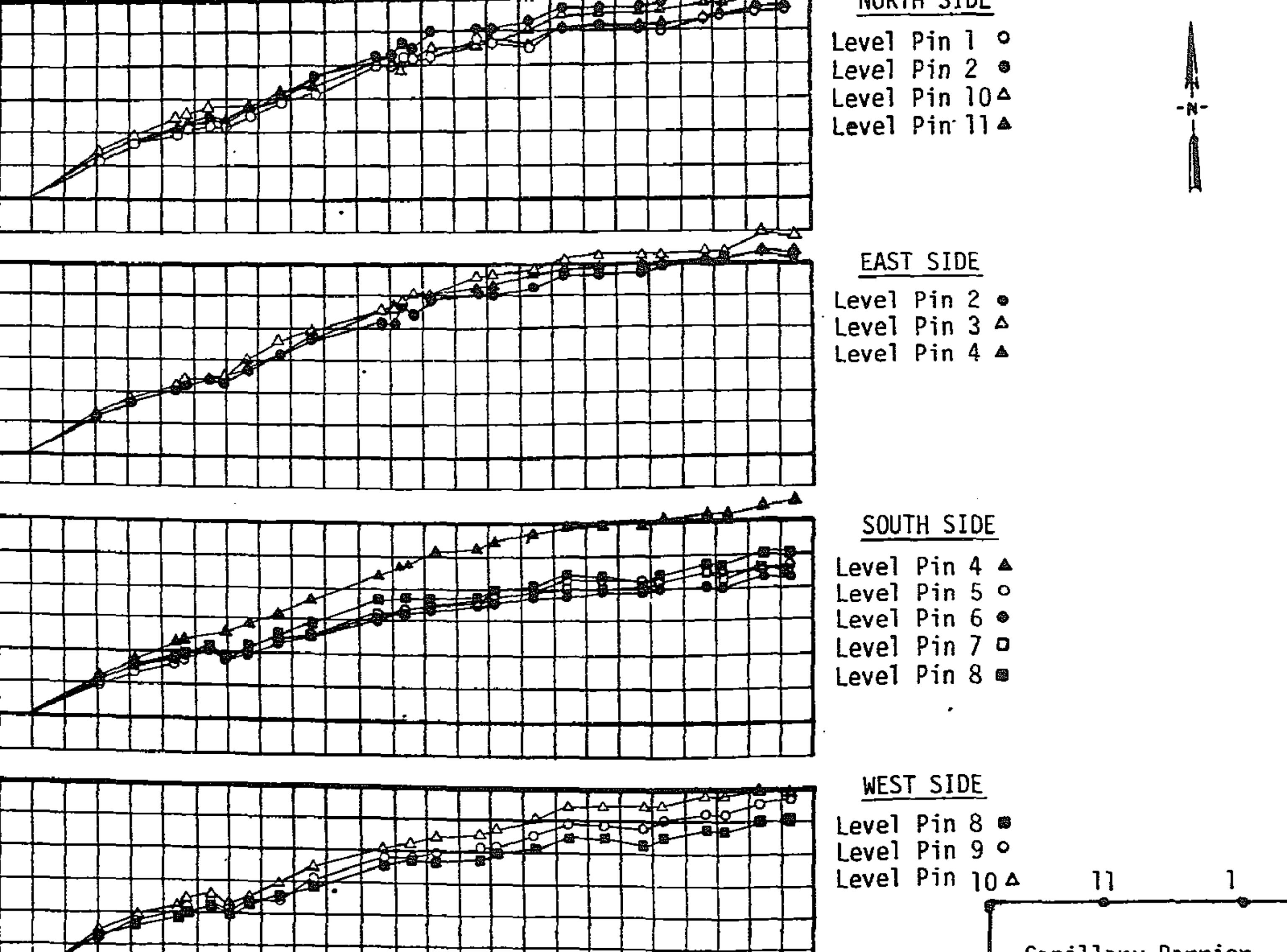
22 shows the vertical movements along each side of the house as of time, and Figure 23 indicates the maximum change in elevation long each side of the house. Data presented is for a performance wo years and represents the climatic effects over approximately al cycles. Both the northeast and southeast corners of the floor approximately the same elevation, with the midpoint along the f the perimeter beam being slightly higher. The southwest corner int; however, change in elevation along the short west side is he south side of this house has the greatest differential move- n corners. Analyzing the configuration of the south side and the ata from level pins 4, 5, 6, 7, and 8, would indicate that climate rubbery, and effects of home maintenance are important considera- he southwest corner and even more so at the change in floor plan on at level pins 6 and 7 where essentially there are two additional vertical planes subjected to the previously mentioned considerations. orner at level pin 6 may be postulated as being subjected to the fect of climate, as accumulated data would indicate. In effect, be considered an extension or continuation of the length of the f the test house where climatic effects are more pronounced in

the vertical movements of all sides of the house are significant Figure 22 , the differential movements as given in Figure 23 , 0 have the greatest physical effect on the house floor slab. e change in elevation between leveling points are relatively icating the effectiveness of this stabilization technique. Finally, and 23 indicate climatic effects are being dampened out and the elevation between leveling points may be attributed, to some extent, e to changes in the subsoil physical properties at different loca- epths around the perimeter of the house.


F M A M J J A S O N D J F M A M J J A S O N D J F M
North Side
East Side
South Side
West Side
-N-
1
2
3
4
5
10
11
Capillary
Barrier
Eagle Ford
.0
.0
.0
0

Differential Elevation: Lot

te	North Side			East Side			South Side			West Side		
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	C
02-76	.010	.120	.305	.008	.096	.244	.009	.108	.274	.018	.216	.
21-76	.039	.468	1.189	.039	.468	1.189	.036	.432	1.097	.040	.480	1.
09-76	.039	.468	1.189	.035	.420	1.067	.047	.564	1.433	.028	.336	.
09-76	.057	.684	1.737	.030	.360	.914	.075	.900	2.286	.008	.096	.
23-76	.046	.552	1.402	.030	.360	.914	.073	.876	2.225	.011	.132	.
09-76	.042	.504	1.280	.033	.396	1.006	.080	.960	2.438	.014	.168	.
29-76	.055	.660	1.676	.012	.144	.366	.089	1.068	2.713	.022	.264	.
21-76	.072	.864	2.195	.026	.312	.792	.107	1.284	3.261	.022	.264	.
16-76	.056	.672	1.707	.030	.360	.914	.092	1.104	2.804	.017	.204	.
09-76	.056	.672	1.707	.030	.360	.914	.100	1.200	3.048	.015	.180	.
27-77	.067	.804	2.042	.045	.540	1.372	.091	1.092	2.774	.025	.300	.
18-77	.066	.792	2.012	.053	.636	1.615	.073	.876	2.225	.046	.552	1.
28-77	.074	.888	2.255	.056	.672	1.707	.072	.864	2.195	.058	.696	1.
14-77	.120	.144	3.658	.060	.720	1.829	.089	1.068	2.713	.091	1.092	2.
04-77	.104	1.248	3.170	.069	.828	2.103	.104	1.248	3.170	.068	.816	2.
19-77	.082	.984	2.499	.059	.708	1.798	.070	.840	2.134	.080	.960	2.
24-77	.072	.864	2.195	.075	.900	2.286	.098	1.176	2.987	.045	.540	1.
10-77	.065	.780	1.981	.078	.936	2.377	.126	1.512	3.840	.014	.168	.
08-77	.060	.720	1.829	.074	.888	2.255	.149	1.788	4.542	.017	.204	.
05-77	.054	.648	1.646	.067	.804	2.042	.148	1.776	4.511	.031	.372	.
07-77	.055	.660	1.676	.075	.900	2.286	.169	2.028	5.151	.049	.588	1.
10-77	.055	.660	1.676	.056	.672	1.707	.201	2.412	6.126	.090	1.080	2.
04-77	.045	.540	1.372	.061	.732	1.859	.206	2.472	6.279	.104	1.248	3.
01-77	.047	.564	1.433	.067	.804	2.042	.214	2.568	6.523	.105	1.260	3.
04-78	.048	.576	1.463	.064	.768	1.951	.220	2.640	6.706	.114	1.368	3.
06-78	.054	.648	1.646	.061	.732	1.859	.232	2.784	7.071	.122	1.464	3.
8-78	.047	.564	1.433	.079	.948	2.408	.183	2.196	5.578	.072	.864	2.


NORTH SIDE
Level Pin 1 ○
Level Pin 2 ●
Level Pin 10 △
Level Pin 11 ▲
N
EAST SIDE
Level Pin 2 ●
Level Pin 3 △
Level Pin 4 ▲
SOUTH SIDE
Level Pin 4 ▲
Level Pin 5 ○
Level Pin 6 ●
Level Pin 7 □
Level Pin 8 ■
WEST SIDE
Level Pin 8 ■
Level Pin 9 ○
Level Pin 10 △
11
1
Capillary Barrier

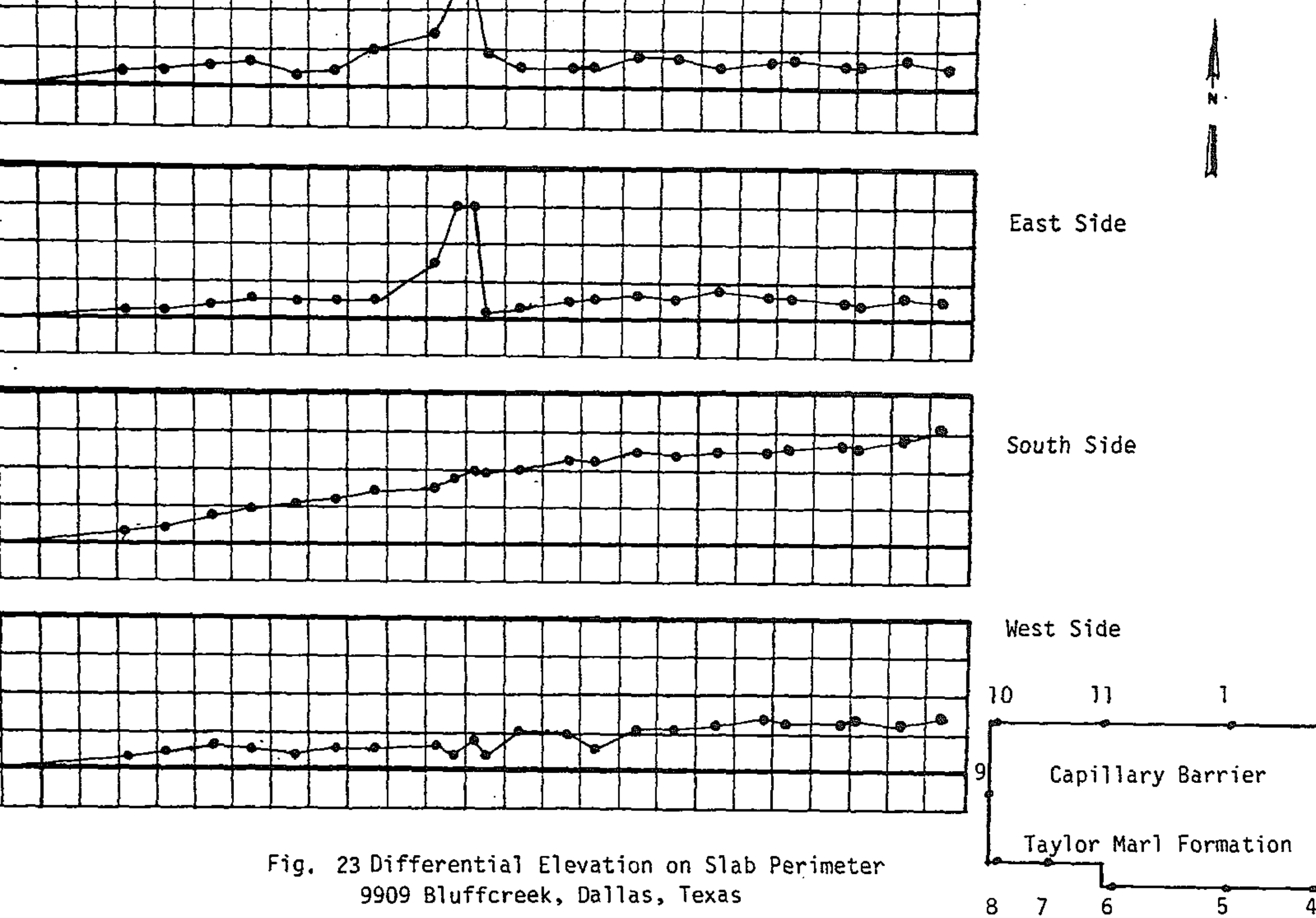


Fig. 23 Differential Elevation on Slab Perimeter
9909 Bluffcreek, Dallas, Texas

Differential Elevation: Lot

	North Side			East Side			South Side			West Side	
e	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
2-76	.012	.144	.366	.008	.096	.244	.012	.144	.366	.010	.120
5-76	.017	.206	.518	.008	.096	.244	.019	.228	.579	.020	.240
3-76	.028	.336	.853	.018	.216	.549	.034	.408	1.036	.029	.348
6-76	.019	.228	.579	.018	.216	.549	.033	.396	1.006	.027	.324
4-76	.021	.348	.640	.024	.288	.732	.040	.480	1.219	.021	.252
0-76	.007	.084	.213	.016	.192	.488	.034	.408	1.036	.019	.228
2-76	.010	.120	.305	.022	.264	.671	.046	.552	1.402	.014	.168
6-76	.014	.168	.427	.024	.288	.732	.041	.492	1.250	.017	.204
8-76	.014	.168	.427	.023	.276	.701	.049	.588	1.494	.027	.326
1-76	.045	.540	1.732	.022	.264	.671	.058	.696	1.768	.027	.326
7-77	.057	.684	1.737	.066	.792	2.012	.068	.816	2.073	.030	.360
1-77	.113	1.356	3.444	.124	1.488	3.780	.076	.912	2.316	.015	.180
4-77	.103	1.236	3.139	.127	1.524	3.871	.082	.984	2.499	.034	.408
4-77	.039	.468	1.189	.008	.096	.0244	.091	.972	2.469	.015	.180
5-77	.022	.264	.671	.029	.348	.884	.097	1.164	2.956	.028	.336
0-77	.027	.324	.823	.009	.108	.274	.086	1.032	2.621	.048	.576
3-77	.025	.300	.762	.023	.276	.701	.091	1.094	2.774	.045	.540
6-77	.026	.312	.792	.024	.288	.732	.089	1.068	2.713	.024	.288
2-77	.038	.456	1.158	.028	.336	.853	.103	1.236	3.139	.048	.576
1-77	.033	.396	1.006	.024	.288	.732	.100	1.200	3.048	.048	.576
5-77	.028	.336	.853	.032	.384	.975	.105	1.260	3.200	.051	.612
1-77	.036	.432	1.097	.028	.336	.853	.105	1.260	3.200	.058	.696
1-77	.043	.516	1.311	.025	.300	.762	.109	1.308	3.322	.051	.612
20-77	.034	.408	1.036	.020	.240	.610	.110	1.320	3.353	.051	.612
06-78	.037	.444	1.128	.016	.192	.488	.109	1.308	3.322	.055	.660
3-78	.036	.432	1.097	.029	.348	.884	.103	1.236	3.139	.055	.660
0-78	.027	.329	.823	.026	.312	.792	.108	1.296	3.292	.060	.720

omparison of Vertical Movements

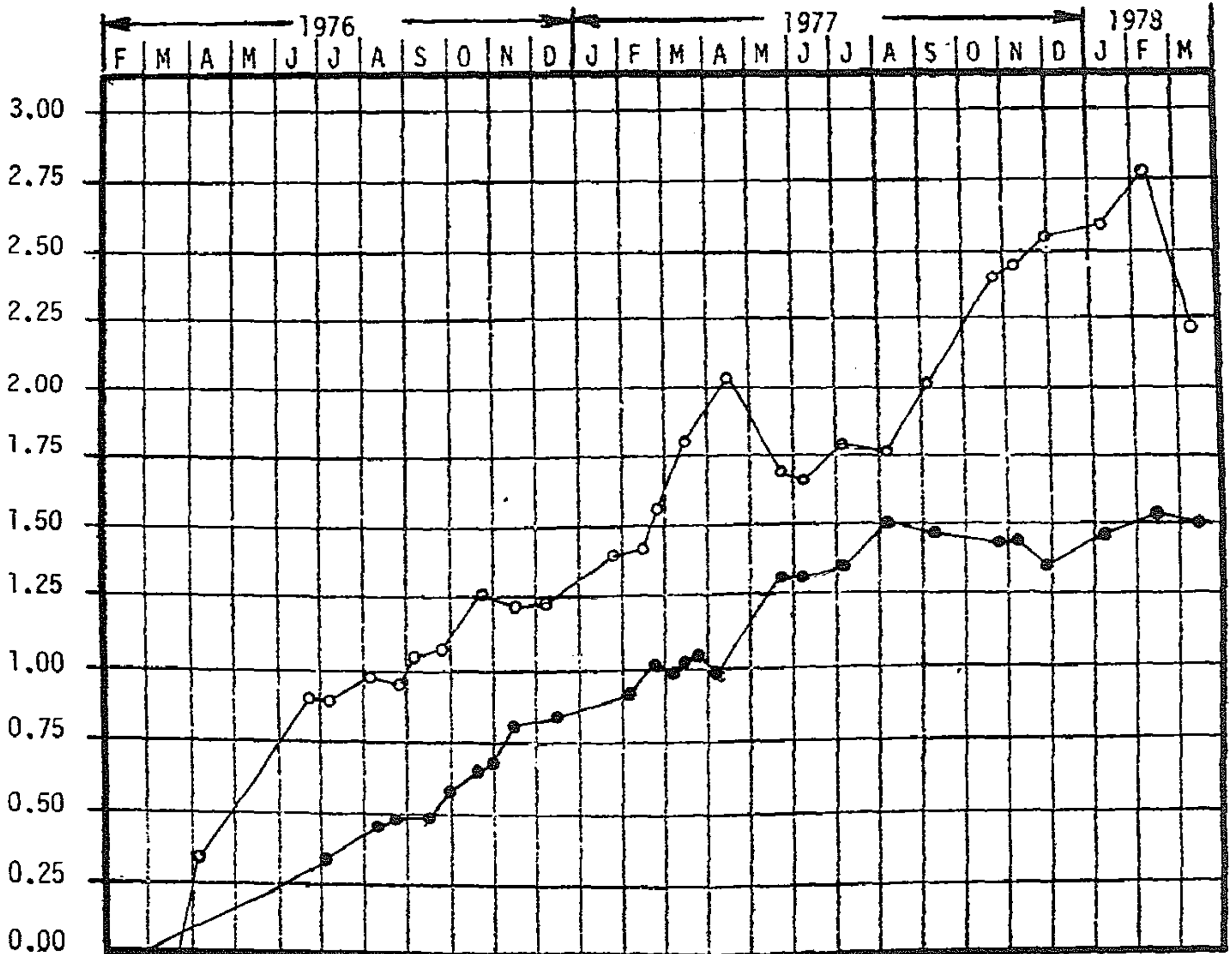
reviously stated, it was observed during this test program the rmation appeared to be more dense than the Eagle Ford geologic unit. 4, and Tables 11 and 12, show a comparison of the capillary barrier stabilization technique. Values plotted are absolute movements and ndication of the activity of each formation for the period of time in this study. It may be possible, at some time in the future, tion of any free water to cross the capillary barrier and be taken mass of subsoil encompassed by the barrier. This could result in l vertical movement in the Taylor formation if the soil clay minerals dditional water to satisfy the mineral double layer requirement. esent time, the maximum vertical movement around the foundation is greater in the Taylor formation than the movement in the Eagle ogic unit for the capillary barrier stabilization technique.

Soil Moisture-Temperature Characteristics - 1642 Cedar Keys Drive, Lewisville, Texas

acquisition for variation in soil moisture content with time, as Figure 25, commenced upon completion of actions associated with ion of the capillary barrier as a subsoil stabilization technique. arent that the increase in moisture content in the subsoil at all interest was relatively successful. The narrow band width of soil contents for each depth and with time indicates the stability of the nd effectiveness of the capillary barrier in inhibiting moisture loss subsoil.

nomaly is apparent for the curves given in Figure 25, at a depth of below the perimeter beam. The moisture cells installed in the boring st side of the house indicate a moisture content significantly less on the other three sides of the test house. This anomaly may be due ion of soil properties at this depth and on the east side of the house. investigation boring log indicated a natural moisture content approxi- ur percent above the Plastic Limit at this depth of interest and it le that less than desired intimacy of contact is existing between the the moisture cell.

average natural soil moisture content from the soils investigation percent to a depth of five feet. The average Plastic Limit to the n was 20 percent. Figure 25 shows the moisture contents at all the subsoil to be at least 2-3 percent above the Plastic Limit and relatively constant values with time. The exception to this state- previously been discussed. In addition, climatic effects are not ng subsoil moisture to any significant degree, within the soil mass d by the capillary barrier.

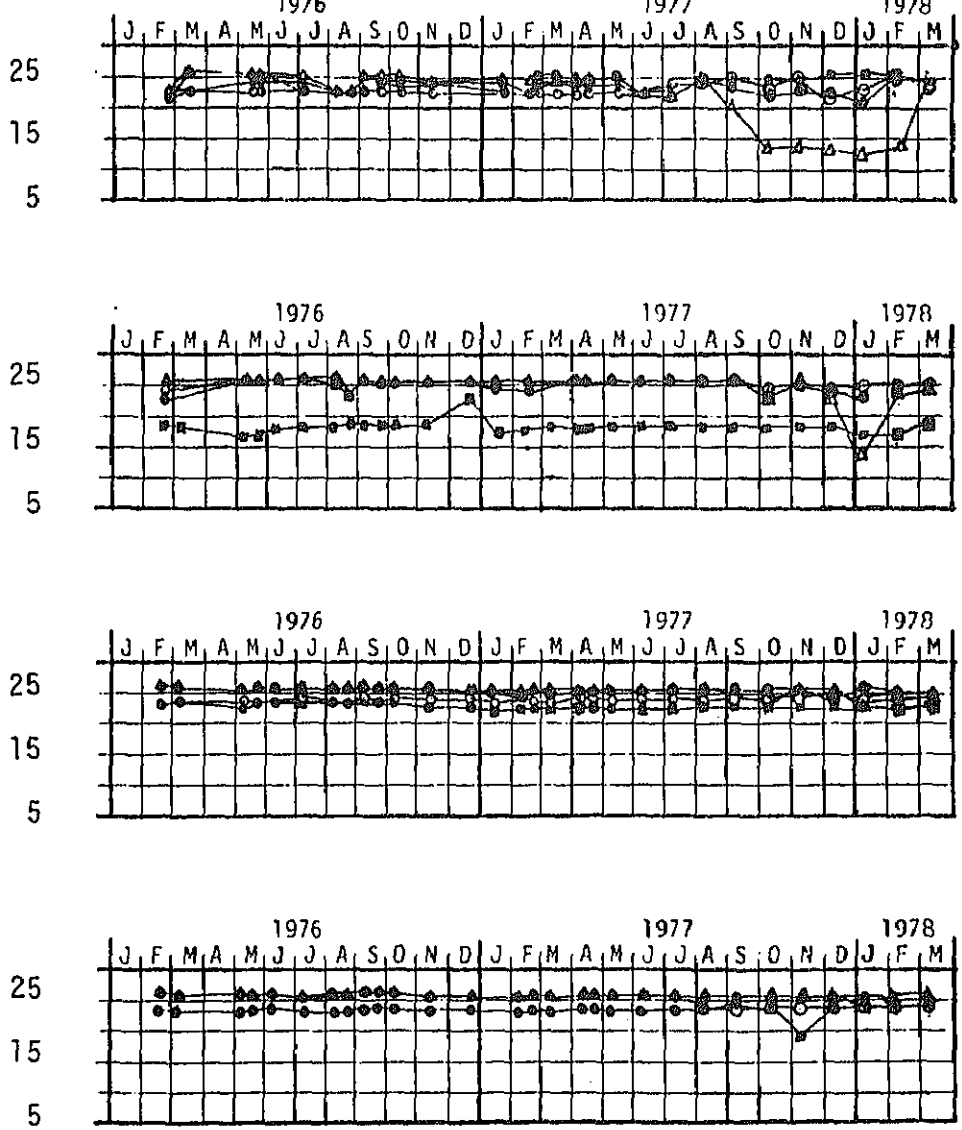


9. 1642 Cedar Keys Drive, Louisville, Texas

Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	Cm.
Apr. 2, 1976	.027	.324	.823
June 21, 1976	.076	.912	2.316
July 9, 1976	.075	.900	2.286
Aug. 9, 1976	.083	.996	2.530
Aug. 23, 1976	.079	.948	2.408
Sep. 9, 1976	.086	1.032	2.621
Sep. 29, 1976	.089	1.068	2.713
Oct. 21, 1976	.108	1.296	3.292
Nov. 16, 1976	.100	1.200	3.048
Dec. 9, 1976	.100	1.200	3.048
Jan. 27, 1977	.116	1.392	3.536
Feb. 18, 1977	.119	1.428	3.627
Feb. 28, 1977	.130	1.560	3.962
Mar. 14, 1977	.150	1.800	4.572
Apr. 14, 1977	.172	2.064	5.243
May 24, 1977	.143	1.716	4.359
June 10, 1977	.140	1.680	4.267
July 8, 1977	.149	1.788	4.542
Aug. 5, 1977	.148	1.776	4.511
Sep. 7, 1977	.169	2.028	5.151
Oct. 10, 1977	.201	2.412	6.126
Nov. 4, 1977	.206	2.472	6.279
Dec. 1, 1977	.214	2.568	6.523
Jan. 4, 1978	.220	2.640	6.706
Feb. 6, 1978	.232	2.784	7.071
Mar. 8, 1978	.183	2.196	5.578
Apr. 3, 1978	.165	1.980	5.029
[illegible]	[illegible]	1.968	4.999

Date	Movement		
	Feet	Inches	Cm.
June 2, 1976	.022	.264	.671
July 5, 1976	.029	.328	.884
Aug. 13, 1976	.038	.456	1.158
Aug. 26, 1976	.040	.480	1.219
Sep. 14, 1976	.040	.480	1.219
Sep. 30, 1976	.048	.576	1.463
Oct. 22, 1976	.054	.648	1.646
Oct. 26, 1976	.057	.684	1.737
Nov. 18, 1976	.068	.816	2.073
Dec. 21, 1976	.071	.852	2.164
Feb. 7, 1977	.078	.936	2.377
Feb. 21, 1977	.084	1.008	2.560
Mar. 4, 1977	.082	.984	2.499
Mar. 14, 1977	.084	1.008	2.560
Mar. 25, 1977	.105	1.260	3.200
Apr. 11, 1977	.082	.984	2.499
May 23, 1977	.112	1.344	3.414
June 9, 1977	.108	1.296	3.292
July 12, 1977	.114	1.368	3.475
Aug. 11, 1977	.124	1.488	3.780
Sep. 15, 1977	.123	1.476	3.748
Oct. 21, 1977	.122	1.464	3.719
Nov. 11, 1977	.121	1.452	3.688
Dec. 20, 1977	.112	1.344	3.414
Jan. 5, 1978	.121	1.452	3.688
Feb. 13, 1978	.130	1.560	3.962
Mar. 10, 1978	.125	1.500	3.962
Apr. 3, 1978	.129	1.548	3.932
May 15, 1978	.127	1.524	3.871



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 25 Soil Moisture Content - Capillary Barrier
1642 Cedar Keys Drive, Lewisville, Texas

The variation of the subsoil temperature with time and for different depths is given in Figure 26. These curves show the characteristic sine wave with changes in climatic temperatures and without significant lag time. At depths of interest, the amplitude of the curve decreases with depth of soil cover. Temperature means and standard deviations are given in Table

4.2.5 Soil Moisture-Temperature Characteristics - 9909 Bluffcreek, Dallas, Texas

Data acquisition for monitoring subsoil moisture characteristics with time is given in Figure 27. Acquisition commenced upon completion of all actions associated with the use of a capillary barrier as a subsoil stabilization technique. It can be seen that the moisture content to depths of interest were increased and maintained well above the Plastic Limit of the soil. Figure 27 also illustrates the dense characteristics of the Taylor formation. The fluctuation of the soil moisture continued over a period of approximately 8-9 months before stabilizing into a narrow band width. It is noted that the fluctuation of magnitude of soil moisture was in a range above the Plastic Limit which was desired.

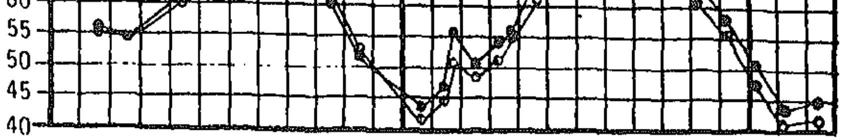
The average natural moisture content of the soil within the depths of interest was 13.8 percent, with the largest variation of moisture content below the Plastic Limit being 7.7 percent. The average Plastic Limit within the depths of interest was 19.4 percent with the variation being approximately 2 percent. It is emphasized that any free water associated with climate or home maintenance is not inhibited from crossing the capillary barrier and being taken into the foundation soil, if the soil moisture demand of the clay minerals is deficient in satisfying the double layer water requirement. The objective for increasing the subsoil moisture content was to be minimum of 2-3 percent above the Plastic Limit of the soil. Any increase in moisture beyond that minimum was a more positive action.

The variation of the soil temperature with time and for different depths is given in figure 28. Again, these curves show a characteristic sine wave with time and without lag time due to climate. The agreement of data at all depths is exceptional and lends credence to the accuracy of other field information. Temperature means and standard deviations are given in Table 14, page 59.

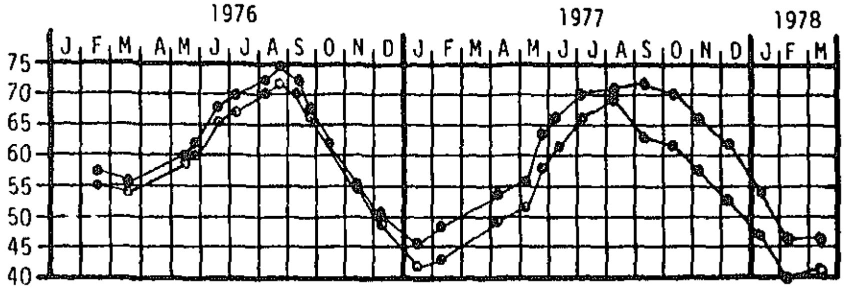
4.2.6 Comparison of Moisture-Temperature Characteristics

The variation of subsoil moisture content with time for these two test houses utilizing a capillary barrier as a subsoil stabilization technique on two geologic formations are similar. From the soils investigation, the

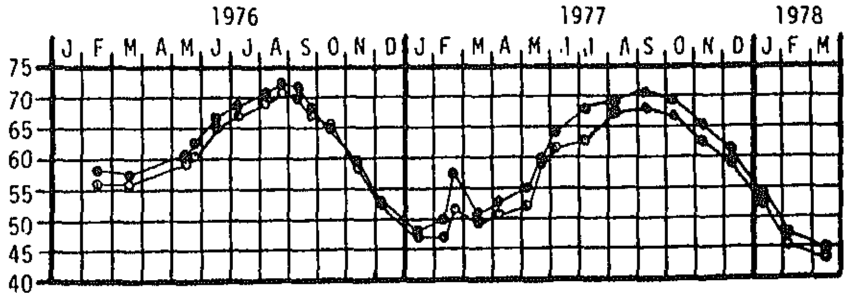
th 1



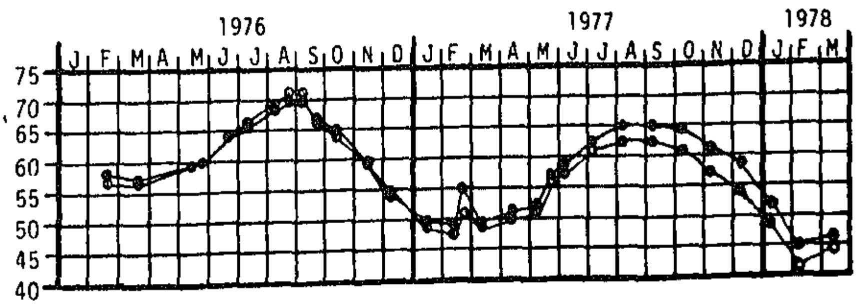
pth 2.5



pth 4



pth 5.5



-Key-

o North and South Side Average

● East and West Side Average

epths refer to feet below grade beam.

Table 13

URE MEANS AND STANDARD DEVIATION

lar Keys Drive, Lewisville, TX

Capillary Barrier

*Depth (ft) 1	2.5	4	5.5
59.24 11.25	59.67 9.42	58.88 8.71	56.70 8.58
62.79 9.82	62.78 8.48	61.95 7.13	59.75 6.42
63.24 9.41	59.83 8.59	60.30 7.06	61.23 7.27
61.10 9.88	dead	60.70 7.95	58.85 7.31

Table 14

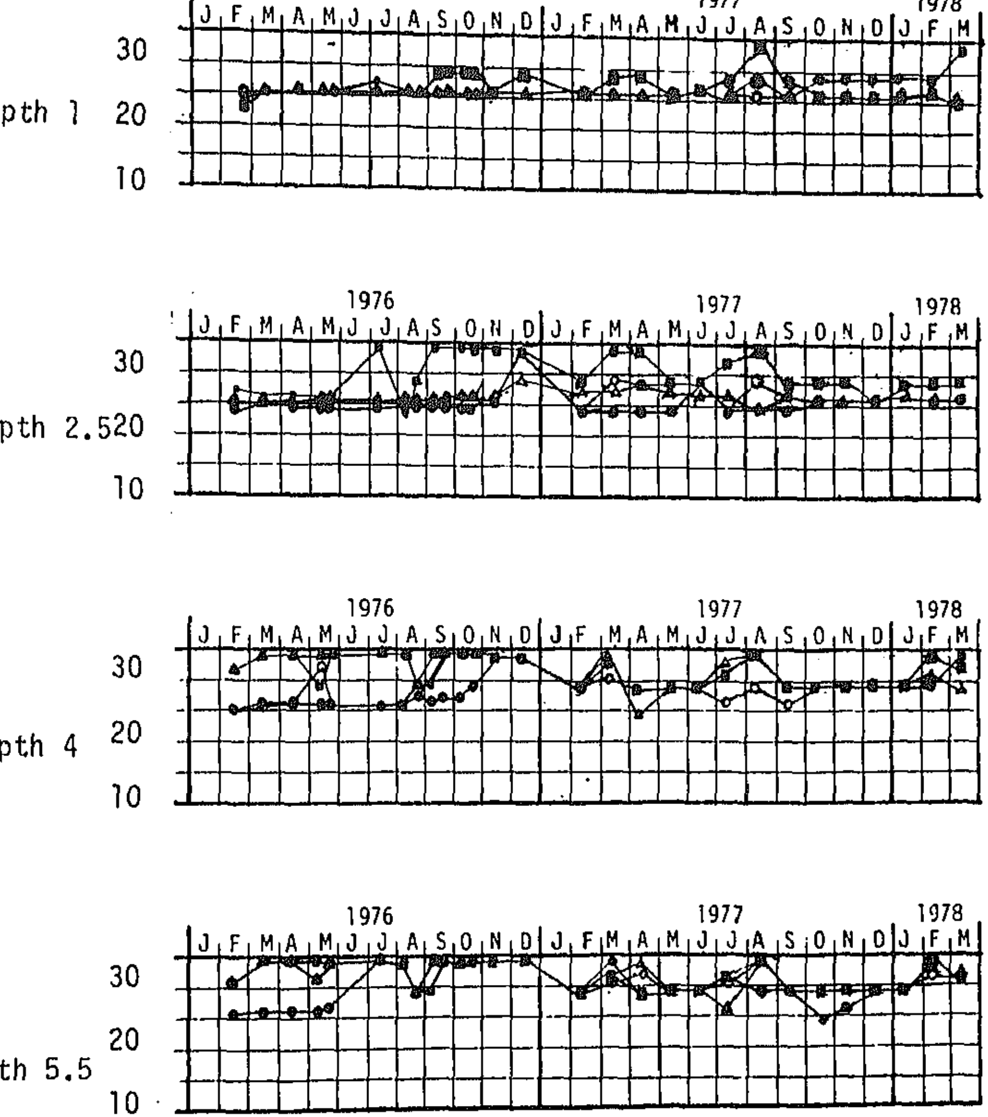
TEMPERATURE MEANS AND STANDARD DEVIATIO

9909 Bluffcreek, Dallas, TX

Capillary Barrier

Location	*Depth (ft) 1	2.5	4	
North	59.02 11.12	59.70 9.56	58.95 8.98	5
East	61.67 9.57	58.70 8.94	58.71 8.05	5
South	62.43 9.08	61.38 8.45	57.10 8.85	6
West	57.43 10.20	60.15 8.74	58.43 7.90	5

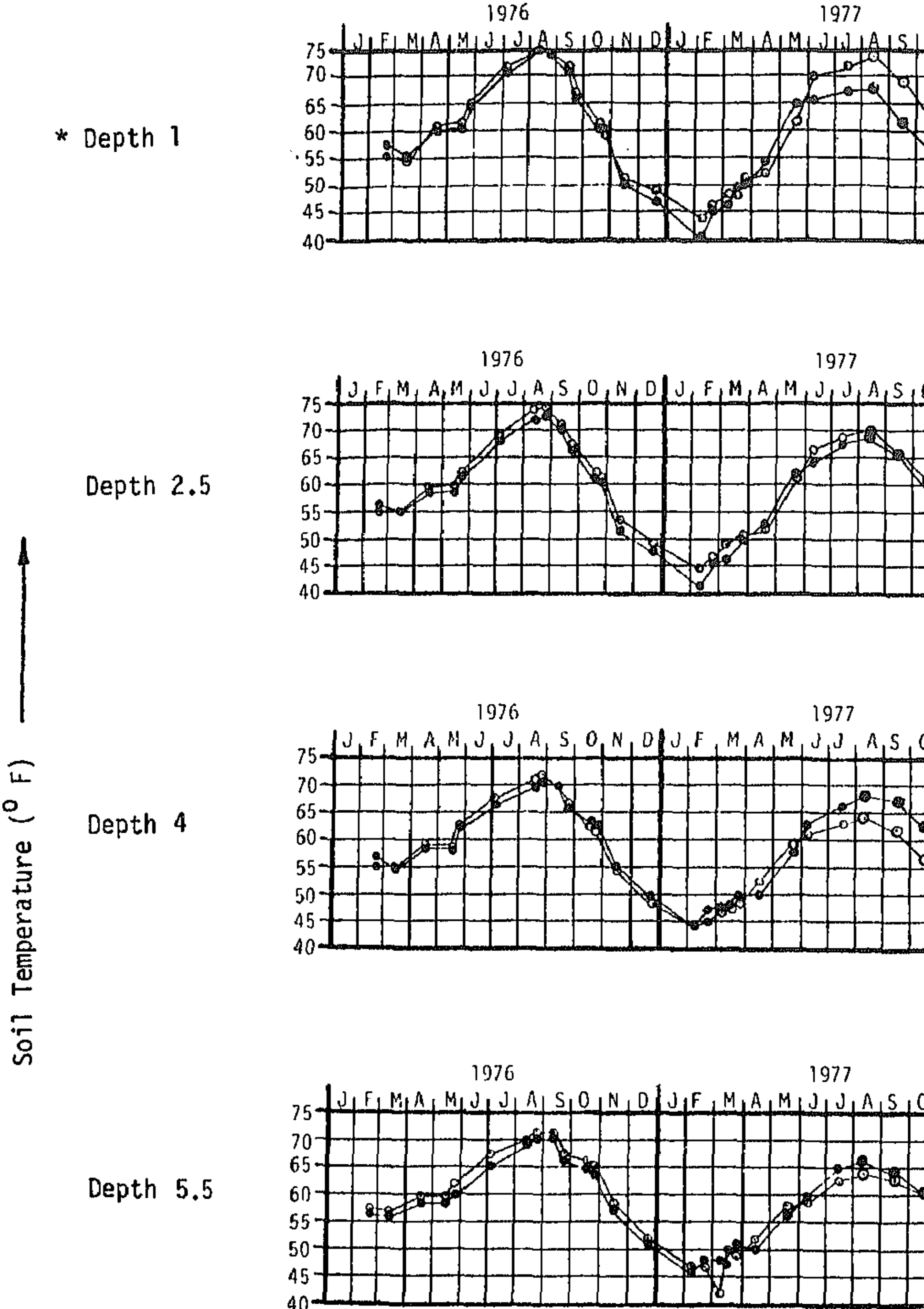
th refers to feet below grade beam.



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 27 Soil Moisture Content - Capillary Barrier
9909 Bluffcreek, Dallas, Texas



Soil Temperature (° F)
* Depth 1
Depth 2.5
Depth 4
Depth 5.5
1976
1977
J F M A M J J A S O N D J F M A M J J A S
75
70
65
60
55
50
45
40

16.6 percent and a maximum variation of 7.7 percent below the
limit. The Plastic Limit of the soil within the depths of interest
percent. The index properties of the soils beneath both houses
ear to be very similar if soil was a homogeneous and isotropic
The significant variable for these values is the natural soil
content, which is approximately 3.5 percent lower for the house at
creek and loacted on the Taylor formation.

gnificant interest is the difference in the percentages of
onite clay minerals in the upper five feet of subsoil at the two
ions. The house at 1642 Cedar Keys Drive, Lewisville, Texas, and
the Eagle Ford formation, contains an average of 15 percent of
onite clay minerals within a five foot depth. The house at 9909
, Dallas, Texas, and located on the residual soils of the Taylor
contained an average of approximately 34.6 percent Montmorillonite
als within a five foot depth from the soil surface. This amounted
age increase of approximately 19.6 percent Montmorillonite clay
or the test house located on the Taylor formation.

quently, the Taylor formation has the potential to exhibit more
nge than the soils of the Eagle Ford formation. This volume
ld be related to a change in water content of the soil. Figures 25
ages 55 and 59, show moisture contents in the foundation soils,
row band widths around the perimeter, at both test houses have
with time at all depths of interest. These data would indicate
tion soil encompassed by the capillary barrier to be relatively

omparison of Figures 26 and 28 , pages 60 and 63 , for subsoil tem-
ariations do not indicate significant differences. Variation of
rature with depth is essentially a function of climate. Within an
g time frame, this would not be a significant variable for magni-
ange in vertical movement. Both referenced figures give an in-
f the insulation properties of the soil. Further justification is
alues of temperature means and standard deviations with depth for
houses given in Tables 13 and 14 , page .

LED RUBBER IMPERVIOUS BARRIERS

ious barriers made of recycled rubber were installed around two
iously damaged by differential movement of the floor slab. The
placed around the house located at 461 Sweetbriar Drive in Lewisville,
second house included in this study is located at 1314 Athens
Mesquite, Texas. This house is founded on the residual soils of
formation.

s of floor plans, trenching, rubber barrier, instrumentation,

oisture, and soils investigation have previously been given. In additio
ontour surveys of each floor slab plan prior and subsequent to taking
orrective actions have also been reported.[1,2]

.3.1 Vertical Movement - 461 Sweetbriar Drive, Lewisville, Texas

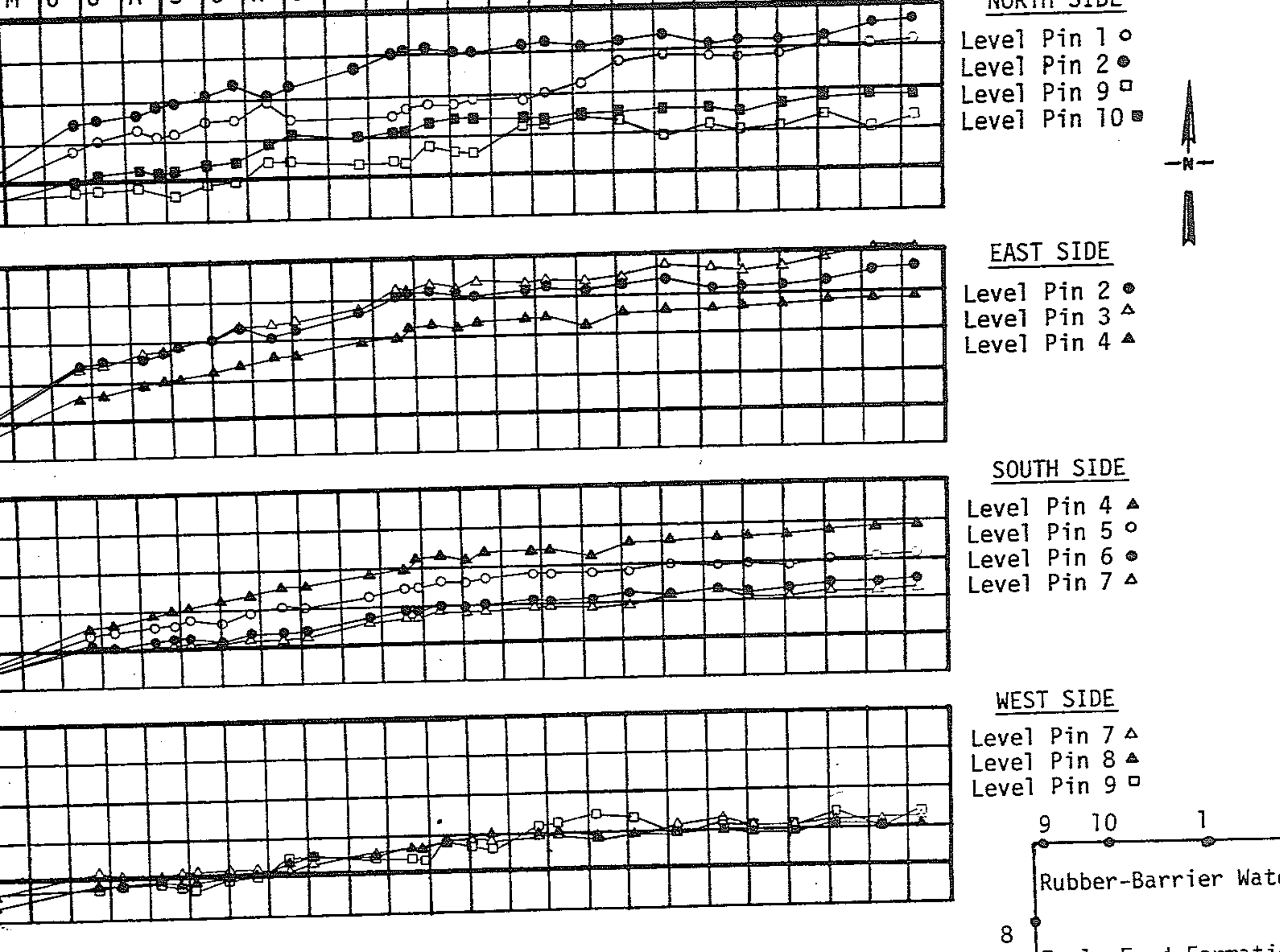
Data acquisition of vertical movements around the foundation perimet
as initiated after the rubber barrier was in place and the foundation so
oisture content increased a minimum of 2-3 percent above the Plastic Lim
pproximately 8,381 gallons of water were added to the subsoil encompasse
y the rubber barrier. The floor slab at 461 Sweetbriar, Lewisville, Tex
d a "cupped" configuration. The perimeter edges were higher than the
nterior of the slab. Water was added at certain points through the rubb
rrier on the outside of the house and at selected locations through the
loor slab on the interior, depending on elevation data.

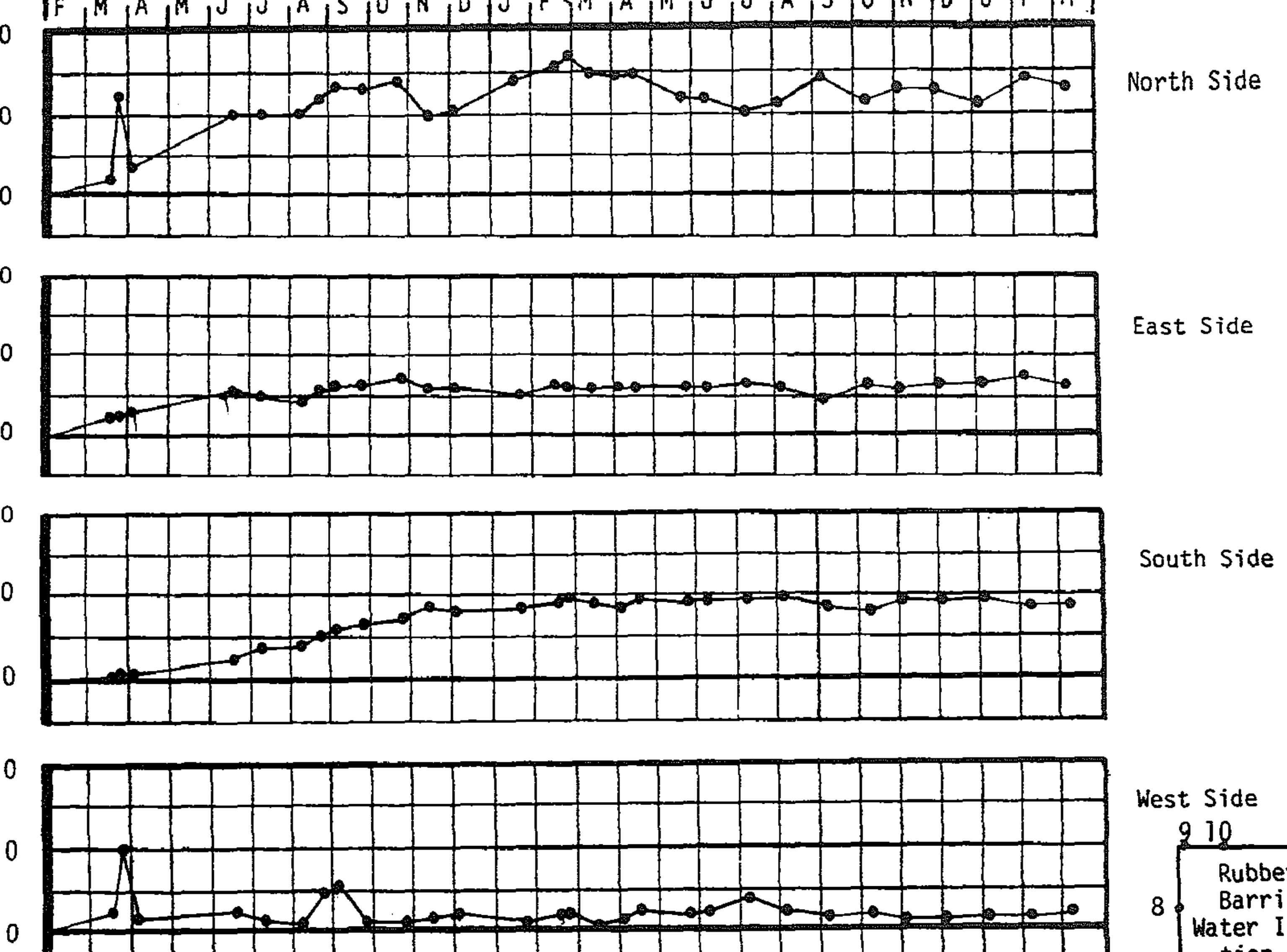
Figure 29 shows the vertical movements along each side of the test
ouse varying with time. The performance period is for approximately 2
ears, which illustrates climatic effects over four seasonal cycles. It
e seen that the high point of the perimeter occurs at level pin 3, or th
idpoint on the east side of the test house. The low point on the perime
ccurs at the Southwest corner and the approximate midpoint of the West
ide, level pins 7 and 8 respectively. Of significance, is the relative
niformity of movement between leveling pins. Equally significant is the
hange in elevation from the high to the low point on the house is approx
tely 1.56 inches across the long side of the house during January 1978.
t would appear that climatic changes are being dampened out and the foun
ion subsoil is relatively stable. The variations in vertical movement c
e attributed to variations in the soil properties within the soil mass e
mpassed by the rubber barrier. Figure 30 illustrates the differential
evation along each side of the house varying with time which shows thes
riations in vertical movements along each side of the test house. The
nformation in tabular form is also given in Table 15 .

3.2 Vertical Movement - 1314 Athens Street, Mesquite, Texas

Data acquisition of vertical movements for this test house located o
oils of the Taylor formation was initiated after all actions associated
tilizing a rubber vertical barrier to inhibit moisture migration caused
imatic effects were complete. Approximately 15,610 gallons of water we
ded to the foundation subsoil encompassed by the rubber barrier. This
est house floor slab had a "domed" shape and water was introduced into t
bsoil in the same manner as discussed in Section 4.3.1.

Figure 31 shows the vertical movement along each side of the test ho
a function of time. Again, the period of data acquisition was for two


Level Pin 1
Level Pin 2
Level Pin 9
Level Pin 10
N
EAST SIDE
Level Pin 2
Level Pin 3
Level Pin 4
SOUTH SIDE
Level Pin 4
Level Pin 5
Level Pin 6
Level Pin 7
WEST SIDE
Level Pin 7
Level Pin 8
Level Pin 9
9
10
1
8


F M A M J J A S O N D J F M A M J J A S O N D J F M
North Side
East Side
South Side
West Side
9 10
8
Rubbe
Barri
Water I

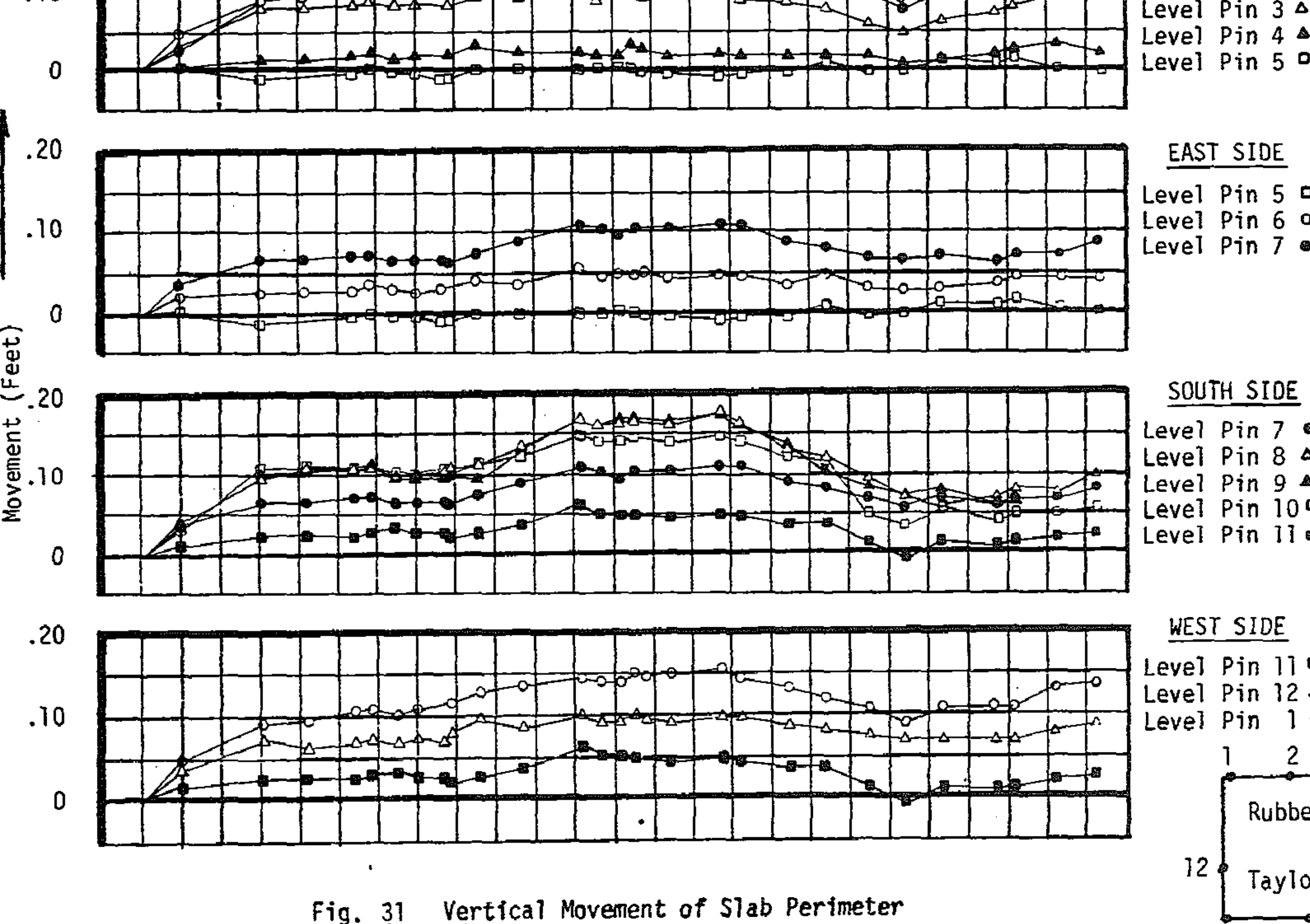


Fig. 31 Vertical Movement of Slab Perimeter
1314 Athens Street, Mesquite, Texas

erimeter occurs at the Southwest corner or at level pin 11. The differen
levation between the West side corners approximates 1.2 inches for Januar
978. Vertical movement appeared to peak approximately six months earlier
nd all sides of the house appear to be stabilizing.

It would be expected the high point on the perimeter to be the Northe
orner and this deviation may be due to the soil properties in this highly
xpansive formation. Significantly, the change in vertical movements alon
ach side are stabilizing and differential elevations between leveling poi
re becoming relatively uniform. Figure 32 and Table 16 illustrate the rela
ive stability around the test house perimeter.

.3.3 Comparison of Vertical Movements

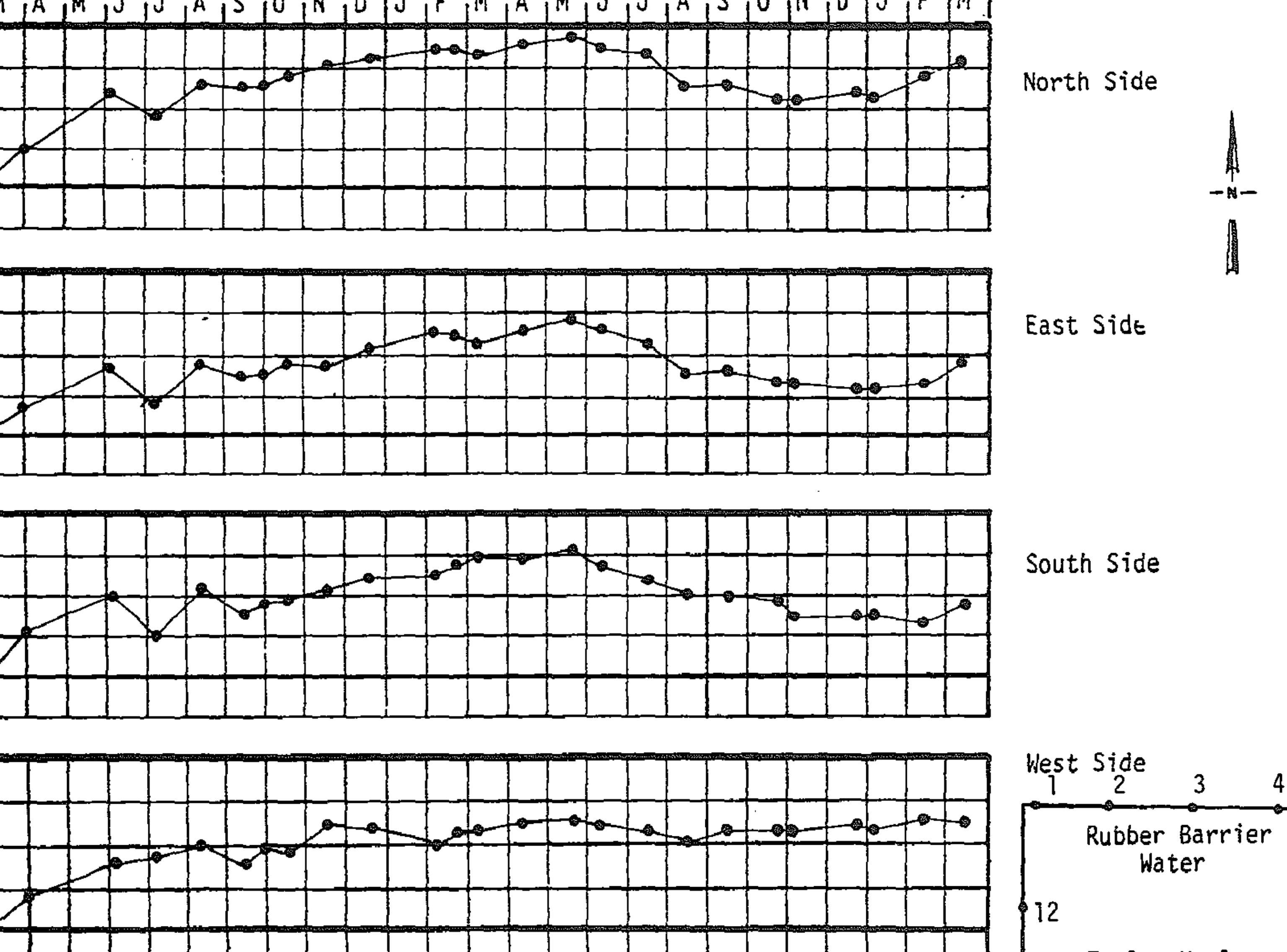
The maximum vertical movement for the test house at 461 Sweetbriar Dr
ewisville, Texas, is greater than the maximum vertical movement of the ho
t 1314 Athens Street, Mesquite, Texas. The magnitude of the differential
levations along each side of the house is less for the house on the Eagle
ord formation. Further, variations of differential movement with time ar
ot as extreme for the house on the Eagle Ford formation. The Taylor form
ion is considered the more active of the two geologic units and a compari
f Figures 29 and 30, pages 63 and 64 with Figures 31 and 32, pages 65 and
upport this statement.

Figure 33 and Tables 17 and 18 were generated by considering the high
nd the low point around the perimeter of each test house and the expected
ariation of movement with time. Consequently, these are absolute values
ive an indication of the comparative activity of the foundation soils be-
eath the two test houses on the two geologic formation.

As the foundation soils for both test houses are encompassed by a rel
ively impermeable vertical barrier, the data given is an indication of th
ctivity of each soil mass in adjusting to a stable configuration. The
mount of deviation or abrupt changes of significant magnitude from a smoo
urve was considered an indication of activity within the encompassed soil
ass. Figure 33 illustrates this concept and shows the soil mass beneath t
ouse on the Eagle Ford formation approaching relative stability, while th
oil mass beneath the house located on the Taylor formation is still under
oing significant adjustment.

.3.4 Soil Moisture-Temperature Characteristics - 461 Sweetbriar Driv
Lewisville, Texas

Data acquisition for variation in soil moisture content with time, as
ven in Figure 34, commenced upon completing all tasks associated with



A M J J A S O N D J F M A M J J A S O N D J F M
North Side
N
East Side
South Side
West Side
1
2
3
4
Rubber Barrier
Water
12

Table 15

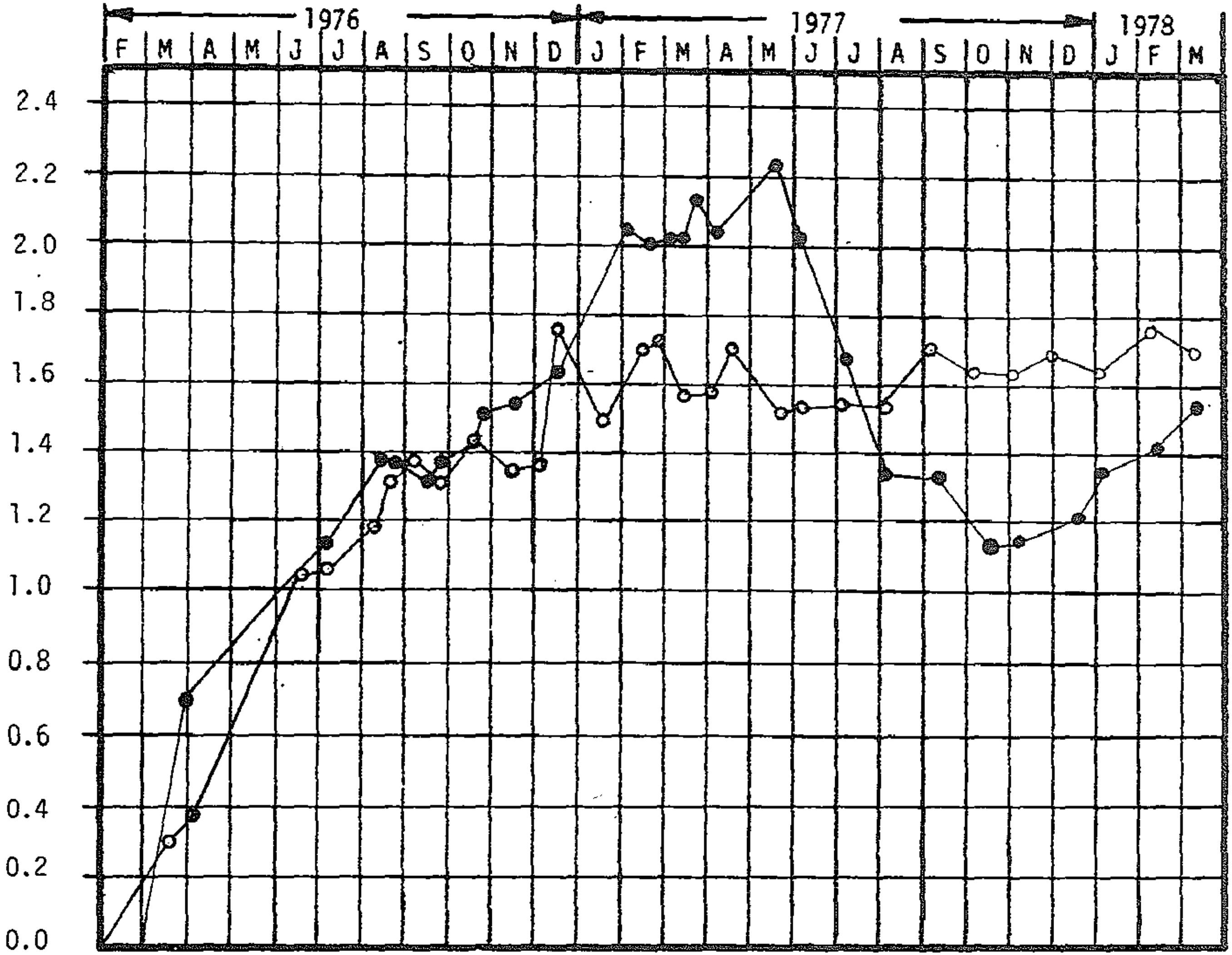
461 Sweetbriar Drive, Lewisville, Texas

Differential Elevation: Lot

	North Side			East Side			South Side			West Side		
te	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	
18-76	.019	.228	.579	.019	.228	.579	.005	.060	.152	.022	.264	
25-76	.107	1.284	3.261	.020	.240	.610	.009	.096	.244	.087	1.044	2
02-76	.030	.360	.914	.024	.288	.732	.007	.084	.213	.013	.156	
21-76	.086	1.032	2.621	.043	.516	1.311	.022	.264	.671	.022	.264	
09-76	.088	1.056	2.682	.042	.504	1.280	.032	.384	.975	.014	.168	
09-76	.089	1.068	2.713	.034	.408	1.036	.045	.540	1.372	.010	.120	
23-76	.105	1.260	3.200	.044	.528	1.341	.035	.420	1.067	.020	.240	
07-76	.113	1.356	3.444	.045	.540	1.372	.048	.576	1.463	.023	.276	
29-76	.109	1.308	3.322	.043	.516	1.311	.055	.660	1.676	.011	.132	
21-76	.119	1.428	3.627	.048	.576	1.463	.060	.720	1.829	.011	.132	
16-76	.081	.972	2.469	.052	.624	1.585	.070	.840	2.134	.013	.156	
02-76	.091	1.092	2.774	.048	.576	1.463	.066	.792	2.012	.015	.180	
21-77	.119	1.428	3.327	.044	.528	1.341	.067	.804	2.042	.013	.156	
18-77	.132	1.584	4.023	.053	.636	1.615	.075	.900	2.286	.015	.180	
28-77	.140	1.680	4.267	.048	.576	1.463	.081	.972	2.469	.016	.192	
14-77	.123	1.476	3.749	.051	.612	1.554	.074	.888	2.256	.006	.072	
04-77	.121	1.452	3.688	.052	.624	1.585	.071	.852	2.164	.013	.156	
19-77	.123	1.476	3.749	.052	.624	1.585	.079	.948	2.408	.108	.216	
24-77	.103	1.236	3.139	.050	.600	1.524	.077	.924	2.347	.015	.180	
-10-77	.100	1.200	3.048	.051	.612	1.554	.078	.936	2.377	.020	.240	
-08-77	.084	1.008	2.560	.055	.660	1.676	.079	.948	2.408	.031	.382	
-05-77	.096	1.152	2.926	.049	.588	1.494	.080	.960	2.438	.020	.240	
-07-77	.112	1.464	3.719	.041	.492	1.250	.070	.840	2.134	.014	.168	
-10-77	.098	1.176	2.987	.054	.648	1.646	.066	.792	2.012	.016	.192	
-02-77	.110	1.320	3.353	.049	.588	1.494	.078	.936	2.377	.009	.108	
-01-77	.107	1.284	3.261	.054	.648	1.646	.077	.924	2.347	.011	.132	
-04-78	.096	1.152	2.926	.055	.660	1.676	.079	.948	2.408	.012	.144	

Differential Elevation: Lot

	North Side			East Side			South Side			West Side		
te	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	C
-31-77	.045	.540	1.372	.033	.396	1.006	.048	.576	1.463	.037	.446	1.
-02-76	.103	1.236	3.139	.076	.912	2.320	.085	1.020	2.591	.071	.852	2.
-05-76	.081	.972	2.469	.039	.468	1.189	.043	.516	1.311	.074	.888	2.
-13-76	.112	1.344	3.414	.077	.924	2.347	.089	1.068	2.713	.085	1.020	2.
-26-76	.084	1.008	2.560	.072	.864	2.195	.088	1.056	2.682	.081	.972	2.
-14-76	.110	1.320	3.353	.069	.828	2.103	.066	.792	2.012	.070	.840	2.
-30-76	.144	1.368	3.475	.071	.852	2.164	.077	.924	2.347	.081	.972	2.
-22-76	.118	1.416	3.597	.078	.936	2.377	.080	.960	2.438	.079	.948	2.
26-76	.126	1.512	3.840	.074	.888	2.256	.083	.996	2.530	.097	1.166	2.
-18-76	.130	1.560	3.962	.075	.900	2.286	.089	1.068	2.713	.104	1.248	3.
21-76	.136	1.632	4.145	.089	1.068	2.713	.100	1.200	3.048	.100	1.200	3.
07-77	.145	1.740	4.420	.110	1.320	3.353	.110	1.320	3.353	.084	1.008	2.
21-77	.145	1.740	4.420	.105	1.260	3.200	.117	1.404	3.566	.092	1.104	2.
04-77	.140	1.680	4.267	.093	1.116	2.835	.123	1.476	3.749	.094	1.128	2.
14-77	.151	1.812	4.602	.105	1.260	3.200	.123	1.476	3.749	.105	1.260	3.
11-77	.154	1.848	4.694	.111	1.332	3.383	.122	1.464	3.719	.104	1.248	3.
23-77	.162	1.944	4.938	.119	1.428	3.627	.132	1.584	4.023	.107	1.284	3.
09-77	.150	1.800	4.572	.114	1.368	3.475	.118	1.416	3.597	.099	1.188	3.
12-77	.136	1.632	4.145	.094	1.128	2.865	.101	1.212	3.078	.097	1.164	2.
11-77	.111	1.332	3.383	.073	.876	2.225	.086	1.032	2.621	.086	1.032	2.
15-76	.110	1.320	3.353	.072	.864	2.195	.083	.996	2.530	.095	1.140	2.
21-77	.093	1.116	2.835	.058	.696	1.768	.077	.924	2.347	.096	1.152	2.
11-77	.098	1.176	2.987	.056	.672	1.707	.064	.768	1.951	.096	1.152	2.
20-77	.102	1.224	3.109	.052	.624	1.585	.063	.756	1.920	.101	1.212	3.
05-78	.097	1.164	2.957	.052	.624	1.585	.062	.744	1.890	.097	1.164	2.
3-78	.118	1.416	3.597	.061	.732	1.859	.058	.696	1.768	.107	1.283	3.2
0-78	.130	1.560	3.962	.082	.984	2.499	.080	.960	2.438	.106	1.272	3.2



o 461 Sweetbriar Drive, Lewisville, Texas - Eagle Ford Formation

Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	Cm.
Mar. 18, 1976	.024	.288	.732
Mar. 25, 1976	-	-	-
Apr. 2, 1976	.032	.384	.975
June 21, 1976	.086	1.032	2.621
July 9, 1976	.088	1.056	2.682
Aug. 9, 1976	.099	1.188	3.018
Aug. 23, 1976	.109	1.308	3.322
Sep. 7, 1976	.116	1.392	3.536
Sep. 29, 1976	.109	1.308	3.322
Oct. 21, 1976	.119	1.428	3.627
Nov. 16, 1976	.112	1.344	3.414
Dec. 2, 1976	.114	1.368	3.475
Jan. 21, 1977	.124	1.488	3.780
Feb. 18, 1977	.143	1.716	4.359
Feb. 28, 1977	.144	1.728	4.389
Mar. 14, 1977	.131	1.572	3.993
Apr. 4, 1977	.133	1.596	4.054
Apr. 19, 1977	.143	1.716	4.359
May 24, 1977	.127	1.524	3.871
June 10, 1977	.129	1.548	3.932
July 8, 1977	.130	1.560	3.962
Aug. 5, 1977	.129	1.548	3.932
Sep. 7, 1977	.143	1.716	4.359
Oct. 10, 1977	.136	1.632	4.145
Nov. 2, 1977	.136	1.632	4.145
Dec. 1, 1977	.140	1.680	4.267
Jan. 4, 1978	.137	1.644	4.176

Date	Movement		
	Feet	Inches	Cm.
Mar. 31, 1976	.058	.696	1.768
June 2, 1976	.117	1.404	3.566
July 5, 1976	.094	1.128	2.865
Aug. 13, 1976	.116	1.392	3.536
Aug. 26, 1976	.114	1.368	3.475
Sep. 14, 1976	.110	1.320	3.353
Sep. 30, 1976	.114	1.368	3.475
Oct. 22, 1976	.119	1.428	3.627
Oct. 26, 1976	.126	1.512	3.840
Nov. 18, 1976	.130	1.560	3.962
Dec. 21, 1976	.136	1.632	4.145
Feb. 7, 1977	.171	2.052	5.212
Feb. 21, 1977	.167	2.004	5.090
Mar. 4, 1977	.169	2.028	5.151
Mar. 14, 1977	.169	2.028	5.151
Mar. 25, 1977	.180	2.160	5.486
Apr. 11, 1977	.172	2.064	5.243
May 23, 1977	.187	2.244	5.700
June 9, 1977	.169	2.028	5.151
July 12, 1977	.140	1.680	4.267
Aug. 11, 1977	.111	1.332	3.333
Sep. 15, 1977	.110	1.320	3.353
Oct. 21, 1977	.096	1.152	2.926
Nov. 11, 1977	.098	1.176	2.987
Dec. 20, 1977	.102	1.224	3.109
Jan. 5, 1978	.097	1.164	2.957
Feb. 13, 1978	.118	1.416	3.597
Mar. 10, 1978	.130	1.560	3.962
Apr. 3, 1978	.132	1.580	4.023
May 15, 1978	.130	1.560	3.962

ccurs well above the average Plastic Limit of the soil which was
ned to be 22.4 percent in the upper five feet of soil.

average natural moisture content of the foundation subsoil at this
se on the Eagle Ford formation was 18.28 percent to a five foot depth.
num deviation of natural moisture below the Plastic Limit was 13.7
above the Plastic Limit, approximately 8,381 gallons of water were
the subsoil. Figure 34, shows the moisture contents at the house
at all depths of interest.

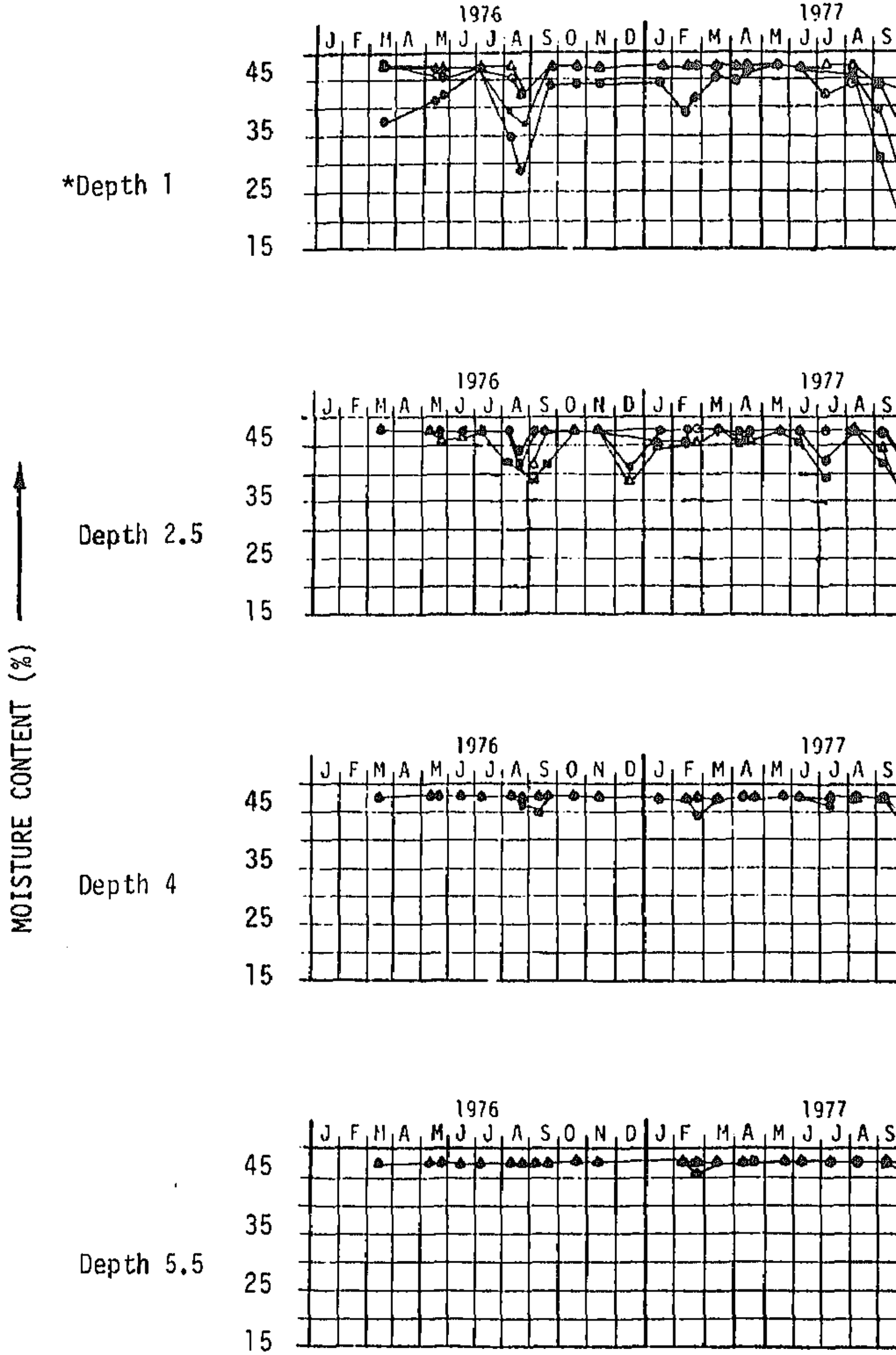
e abrupt variation was noted in data values for moisture contents,
rly in the upper soil depths. It was anticipated this would occur
rst few months after water was added to the subsoil while diffusion
re was taking place. Abrupt changes beyond that point in time were
d errors by research personnel in reading instrument values. Signi-
uctuation in the moisture cell on the West side of the house began
1977, and decreased down to a value of 15 percent. This instrument
evaluated, but it would appear that failure has occurred. In most
, the variations occurring in soil moisture as given in Figure 34 are
e the desired minimum of approximately 25 percent.

variation of soil temperature at all depths of interest, varying with
given in Figure 35. These curves show the desired characteristic
shape, with amplitude decreasing with soil depth. The values of
re data did not indicate any influence of the climatic cycle, and
the performance of soil as an insulating medium. The values of
means and deviations are given in Table 19.

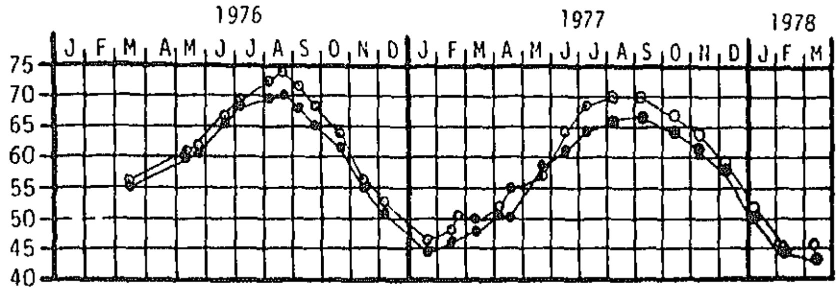
Soil Moisture-Temperature Characteristics - 1314 Athens Street, Mesquite, Texas

acquisition for variation in soil moisture content with time, as
Figure 36, commenced upon completing all tasks associated with
the rubber moisture barrier as a subsoil stabilization technique.
e variation with time is noted in the upper depths of interest, the
curs well above the average Plastic Limit of the soil which was
ed to be 22.4 percent in the upper five feet of soil.

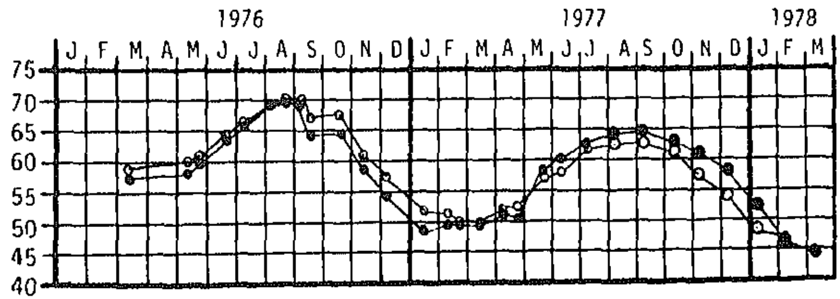
average natural moisture content of the foundation subsoil at this
e on the Taylor formation was 20.68 percent to a five feet depth.
um deviation of natural moisture below the Plastic Limit was 8.5
To raise the moisture content of the subsoils a minimum of 2-3
bove the average Plastic Limit, approximately 15,610 gallons of
e added. This increase in water volume was 1.86 times the amount of
ed to the test house soils, using the same subsoil stabilization
, on the Eagle Ford formation. This increased volume of water was
to bring the moisture content of the subsoil in the upper five feet


MOISTURE CONTENT (%)
*Depth 1
Depth 2.5
Depth 4
Depth 5.5
1976
1977
J F M A M J J A S O N D J F M A M J J A S
45
35
25
15

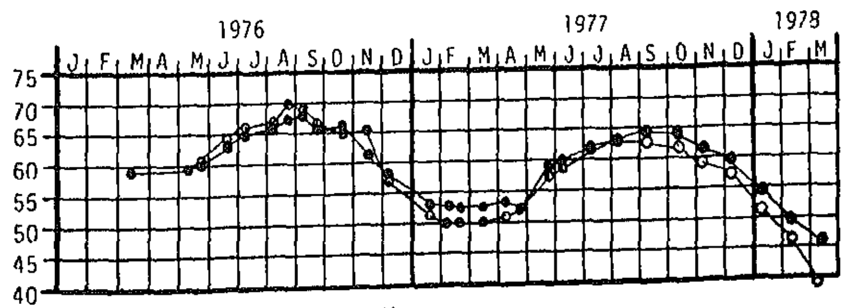
n 2.5



h 4



h 5.5



-Key-

∘ North and South Side Average
• East and West Side Average

ths refer to feet below grade beam.

Table 19

PERATURE MEANS AND STANDARD DEVIATION

51 Sweetbriar Drive, Lewisville, TX

Rubber Barrier-Water

l ion	*Depth (ft) 1	2.5	4	5.5
	61.53 10.46	59.00 8.98	59.47 6.84	58.16 7.57
	57.35 9.41	57.94 8.52	59.21 7.55	59.53 5.98
	57.69 9.59	62.95 9.10	60.00 7.28	60.45 6.48
	59.24 9.87	60.61 8.23	58.47 6.99	59.79 6.08

Table 20

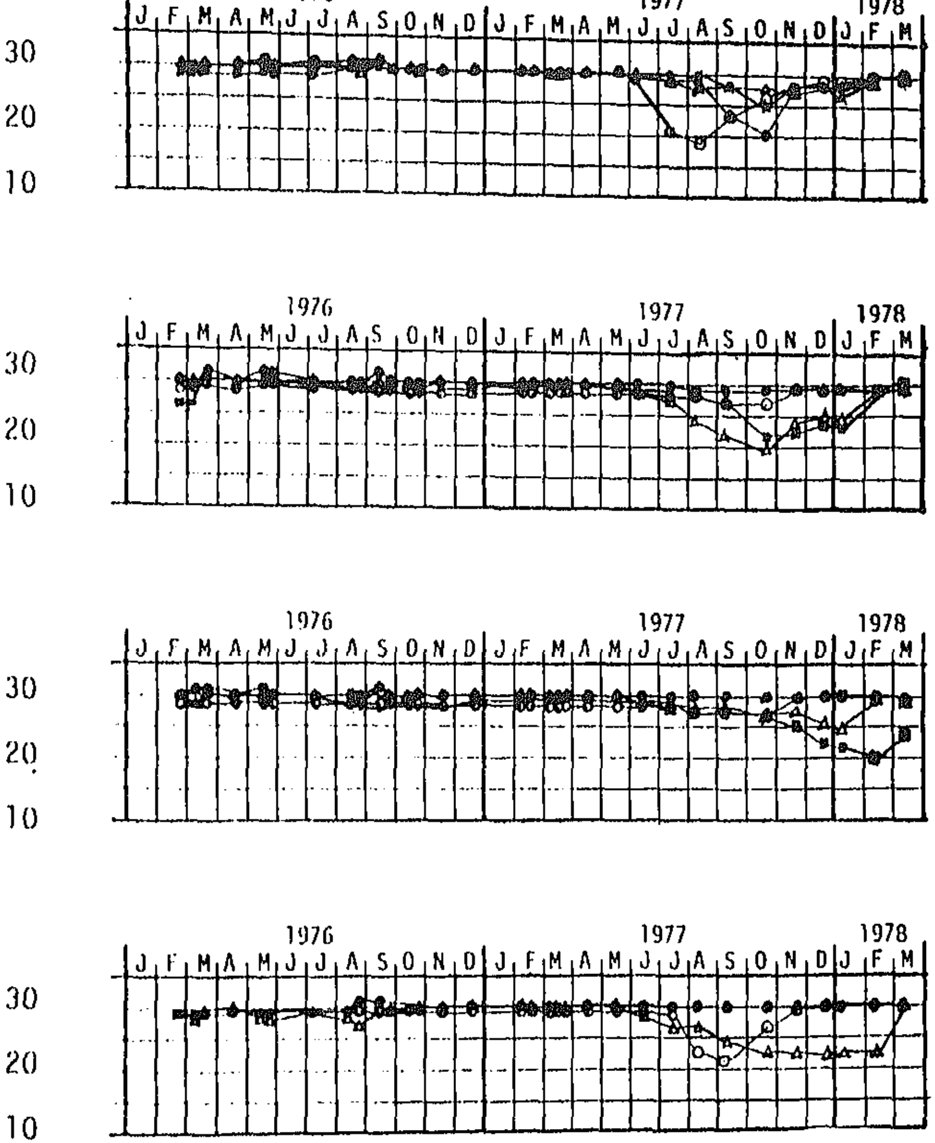
TEMPERATURE MEANS AND STANDARD DEV

1314 Athens Street, Mesquite,

Rubber Barrier-Water

Location	*Depth (ft) 1	2.5	4
North	61.36 10.50	58.05 8.13	60.73 8.30
East	58.55 9.29	60.82 8.66	57.91 7.90
South	62.30 8.24	63.18 8.92	59.98 7.07
West	60.00 9.18	61.00 7.06	dead

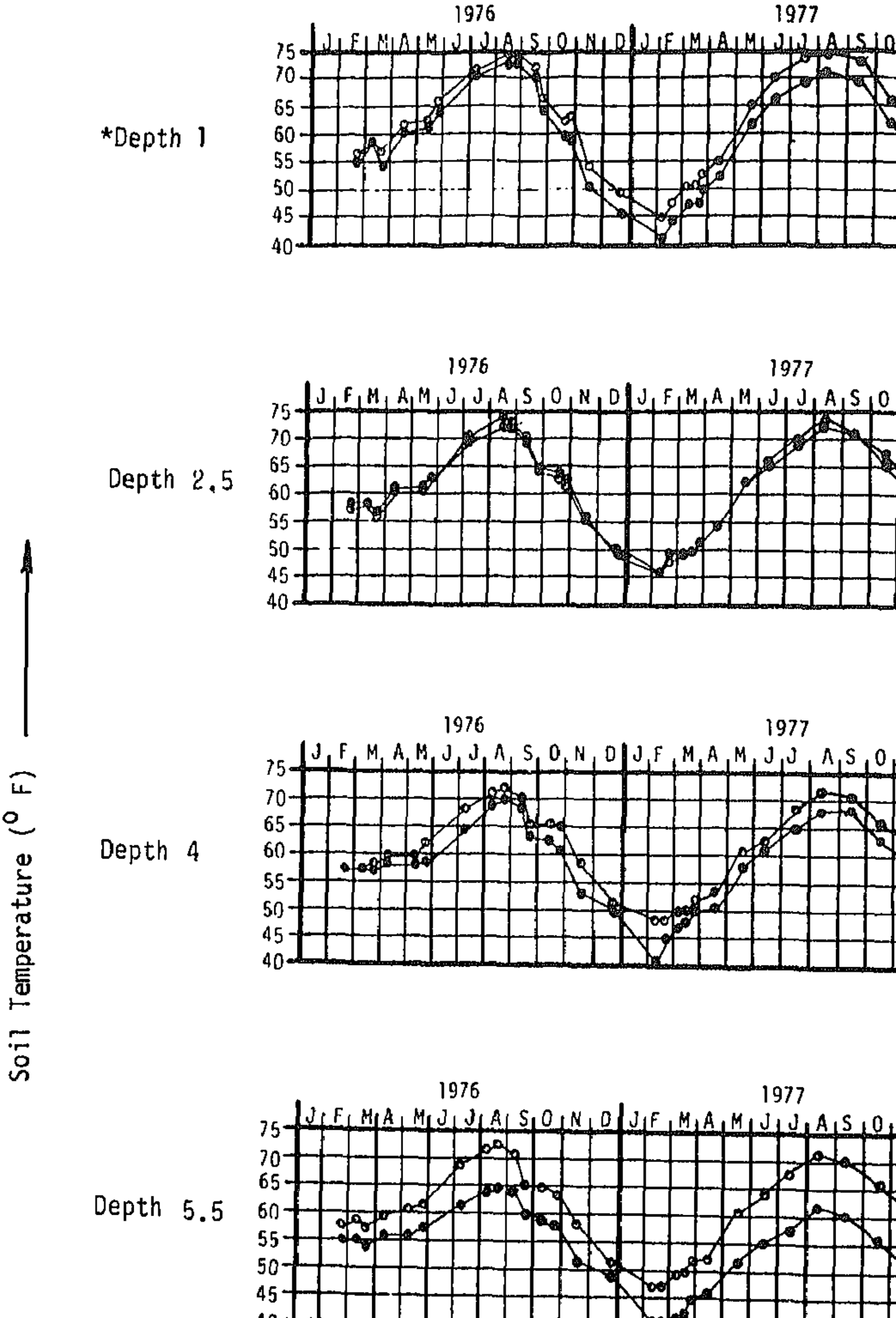
*Depth refers to feet below grade beam.



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 36 Soil Moisture Content - Rubber Barrier
1314 Athens Street, Mesquite, Texas



Soil Temperature (° F)
*Depth 1
Depth 2.5
Depth 4
Depth 5.5
1976
1977
J F M A M J J A S O N D J F M A M J J A S O
75
70
65
60
55
50
45
40

and the subsoil contained extensive tension cracks and fractures. It is submitted that an undetermined volume of the added water was lost to significant depths in the subsoil and also to soil outside the rubber bar by the ready avenues of escape provided by fractures and cracks in the fo tion subsoil. As the soil expanded and gradually restricted these flow p the increase in soil moisture was obtained in the soil mass surrounded by the rubber barrier.

The variation of the soil temperature with time and for different depths is given in Figure 37 . These curves show the characteristic sine wave shape and amplitude change with depth, and for this test house, more variation in temperature was noted at the lower depths in the subsoil. T can be explained by referring to Table 20 , page 76, which gives the tempe ture means and standard deviations for the test house on the Taylor forma It can be noted that no data is given for depths 4 and 5.5 for the soil boring on the West side of the test house. The thermistor portion of the moisture-temperature cell installed at these two depths became inoperativ short time subsequent to installation. Consequently, the curves plotted Figure 37 indicate average temperatures for the North and South sides of t house, but only the East side temperature readings are plotted for depths and 5.5. In this area, the East side would be protected from climatic va tions much more so than the West side and consequently cooler.

4.3.6 Comparison of Soil Moisture-Temperature Characteristics

The test house at 461 Sweetbriar Drive, Lewisville, Texas, was situat on the residual expansive clays of the Eagle Ford formation. From the so investigation for this test house, it was established that the insitu nat subsoil properties prior to installation of the stabilization technique i cluded an average Plastic Limit of 22.4 percent within the upper five fee Further, the average natural moisture content of the subsoil to the same depth was 18.28 percent. The maximum deviation of the subsoil moisture c tent below the Plastic Limit was approximately 13.7 percent.

The test house at 1314 Athens Street, Mesquite, Texas was located on the residual soils of the Taylor formation, which is also quite expansive From the soils investigation for this test house, the insitu average natu moisture content was 20.68 percent within the upper five feet. The maxim deviation below the Plastic Limit was approximately 8.5 percent. These properties were determined prior to initiating any actions associated wit subsoil stabilization.

The average Plastic Limit of the subsoils beneath the two houses are similar, 22.4 percent and 22 percent respectively. The natural insitu mo ture content of the subsoil for the house on the Eagle Ford formation and for the house on the Taylor formation vary by approximately 2.4 percent, not a significant variation for differences in magnitude of monitored mo content shown in Figures 34 and 36, pages 74 and 77. It was found that

ese two test loactions, a reversal of index properties was noted. The tural moisture content of the Taylor formation was higher and there was gnificantly less deviation in the moisture content below the Plastic Lim an for the house on the Eagle Ford formation 8.5 percent as compared to .7 percent, respectively.

For these two test locations it was found that a reversal occurred in e percentage of the highly expansive clay minerals of the Montmorillonit oup in the upper five feet. For the test house on the Eagle Ford format average of 36 percent of Montmorillonite was evidenced within the depth interest, while for the test house on the Taylor formation, the average s 24.4 percent, or a difference of approximately 11.6 percent. As both rmations are sedimentary deposits associated with the same general geolo me, this was not considered unusual.

The large percentage of Montmorillonite clay minerals within the uppe ve feet of soil for the test house located on the Eagle Ford formation uld result in the significant increase in moisture content within the so ss encompassed by the relatively impermeable rubber barrier. Even thoug ss water volume was introduced into the subsoil, the signficant increase rcentage of Montmorillonite clay minerals with their high specific surfa ea and affinity for free water would justify the increased moisture cont e lower natural water content of the soil, and the high deviation of the situ moisture content below the Plastic Limit of the soil would be contr ting factors. Consequently, adjustment of the soil moisture contents wi me and the aforementioned expansive characteristics would result in in- eased vertical movement.

For the test house at 1314 Athens Street, Mesquite, Texas, the variat soil moisture with time as given in Figure 36 , page 80 , is relatively iform at all depths of interest. It is reiterated that a much larger vo water was introduced into the subsoil surrounded by the relatively impe able rubber barrier. The soils of this formation are dense and fracture d it was believed a significant quantity of water was able to migrate to eat dephts and outside of the barrier perimeter. Consequently, a much eater mass of soil, also containing a significant percentage of Montmori ay, was able to experience its swell potential.

A comparison of the variations in soil temperature with time from dat ven in Figures 35 and 37 , and Tables 19 and 20 , pages 75 , 78 , 76 a , are relatively similar. It may be concluded that both referenced fig uld exhibit like variations with depth and time, if the thermistors in t wer soil depths on the West side of the house at 1314 Athens Street, Mes xas, had not malfunctioned. Soils on the West side of a house in this a e subjected to more intense variation with time and as a consequence, th mperature variations given in Figure 37 , page 78 , for depths 4 and 5.5 flect North and South side temperature averages for one curve, but only st side temperature data for the second curve at each depth, for this te

floor plans, trenching, concrete barrier, instrumentation, permanent bench mark, costs, increasing foundation soil ls investigation have previously been given. In addition, f each floor slab plan prior and subsequent to corrective been reported.(1,2)

al Movement - 1137 Eastwood Drive, Lewisville, Texas

tion of vertical movements around the foundation perimeter er the concrete barrier was in place and the foundation soil increased a minimum of 2-3 percent above the Plastic Limit. 27 gallons of water were added to the subsoil encompassed by ier. The floor slab at 1137 Eastwood Drive, Lewisville, ed" configuration. The perimeter edges were higher than he slab. Water was added to the subsoil from the interior elected locations through the floor slab depending on eleva-

hows the vertical movements along each side of the test house . The performance period is for approximately two years, or matic cycles. It was seen that the high point of the peri- evel pin 11 or the Southwest corner of the test house. The perimeter occurs at level pin 14 or along the East side of data are given for January 1978. The uniformity of movement ter, as indicated by distances between the data points given or eash side of the test house is significant. The maximum on between the high and low points around the perimeter, for approximately 1.74 inches, and the maximum change in elevation points is 0.84 inches. The anticipated low point on the occur at the Southwest corner, and the high point at the North- variation in soil properties in the subsoil mass encompassed arrier could account for this anomaly. The purpose of the barriers was to mitigate or inhibit subsoil volume changes climatic effects.

nd Table 21 show absolute differential movements with time f the test house. The similarity of the differential eleva- he South and West sides and the similarity of the curves for t sides is interesting.

4.4.2 Vertical Movement - 4204 Culmer, Balch Springs, Texas

Data acquisition of vertical movements for this test house located o residual soils of the Taylor formation was initiated after all actions associated with utilizing a concrete barrier to inhibit moisture migratio due to climatic effects were complete. Approximately 13,410 gallons of w were added to the foundation subsoil surrounded by the concrete barrier. This test house floor slab had a "domed" shape and water was introduced i the subsoil by drilling access holes with a masonry drill through the bar to insert an injection lance. All holes around the perimeter were tempor sealed after each injection, and permanently sealed after the desired moi content within the subsoil was established.

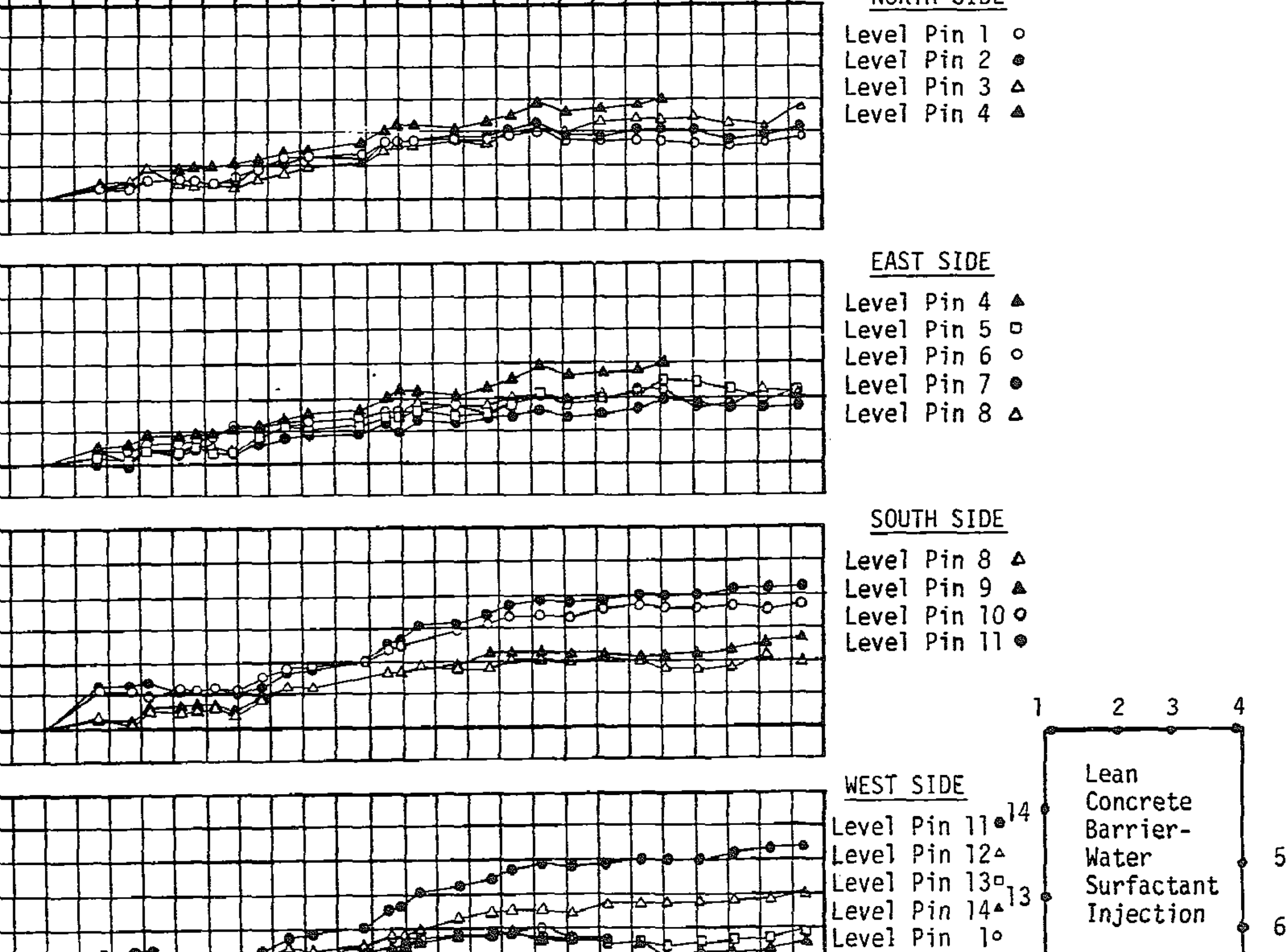
Figure 40 shows the vertical movement variation associated with tim each side of the test house. As before, the performance period approxima 2 years, which illustrates the effects of climate over approximately four seasonal cycles. The high point on the perimeter of this test house also occurred at the Southwest corner or level pin 7 and the low point was at level pin 4 on the East side of the house. These data are for January 19 The uniformity of vertical movement around the perimeter is considered ex ceptional for this expansive clay soil. The vertical movements can be cl studied from the data points given in Figure 40 for each side of this te house. The maximum change in vertical elevation between leveling pins of 0.36 inches for the month of January 1978. The maximum change in vertica movement between the high and low points around the perimeter of the test house, for the same time period, is approximatly 0.78 inch. The small differential movements associated with the lean concrete barrier surround the subsoil mass are attributed to variations of the soil properties with the effected volume.

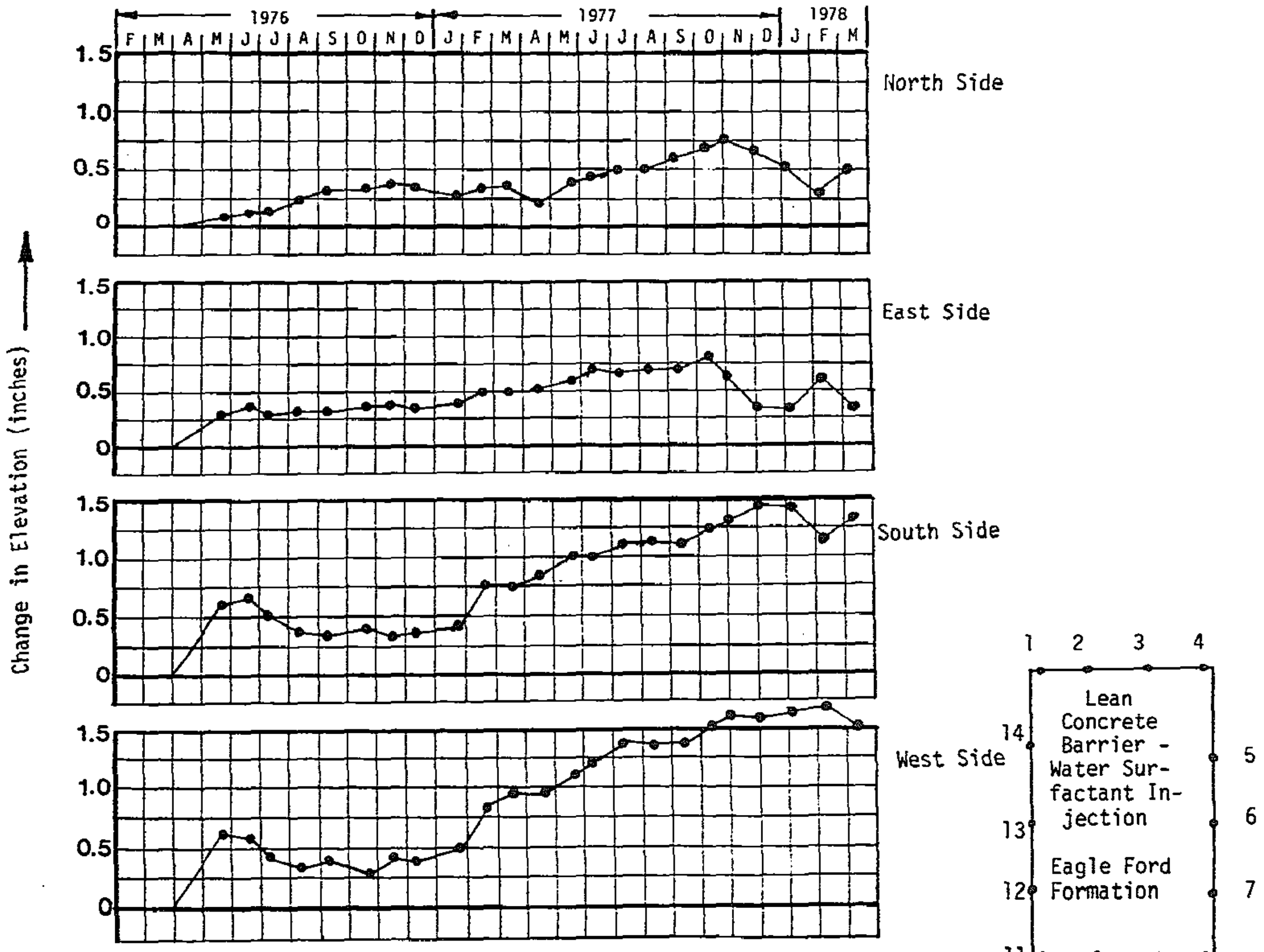
Figure 41 and Table 22 show absolute differential movements with ti along each side of the test house. Figure 41 illustrates the increasing stability of the foundation subsoil with time, and also the lack of influ associated with climatic conditions.

4.4.3 Comparison of Vertical Movements

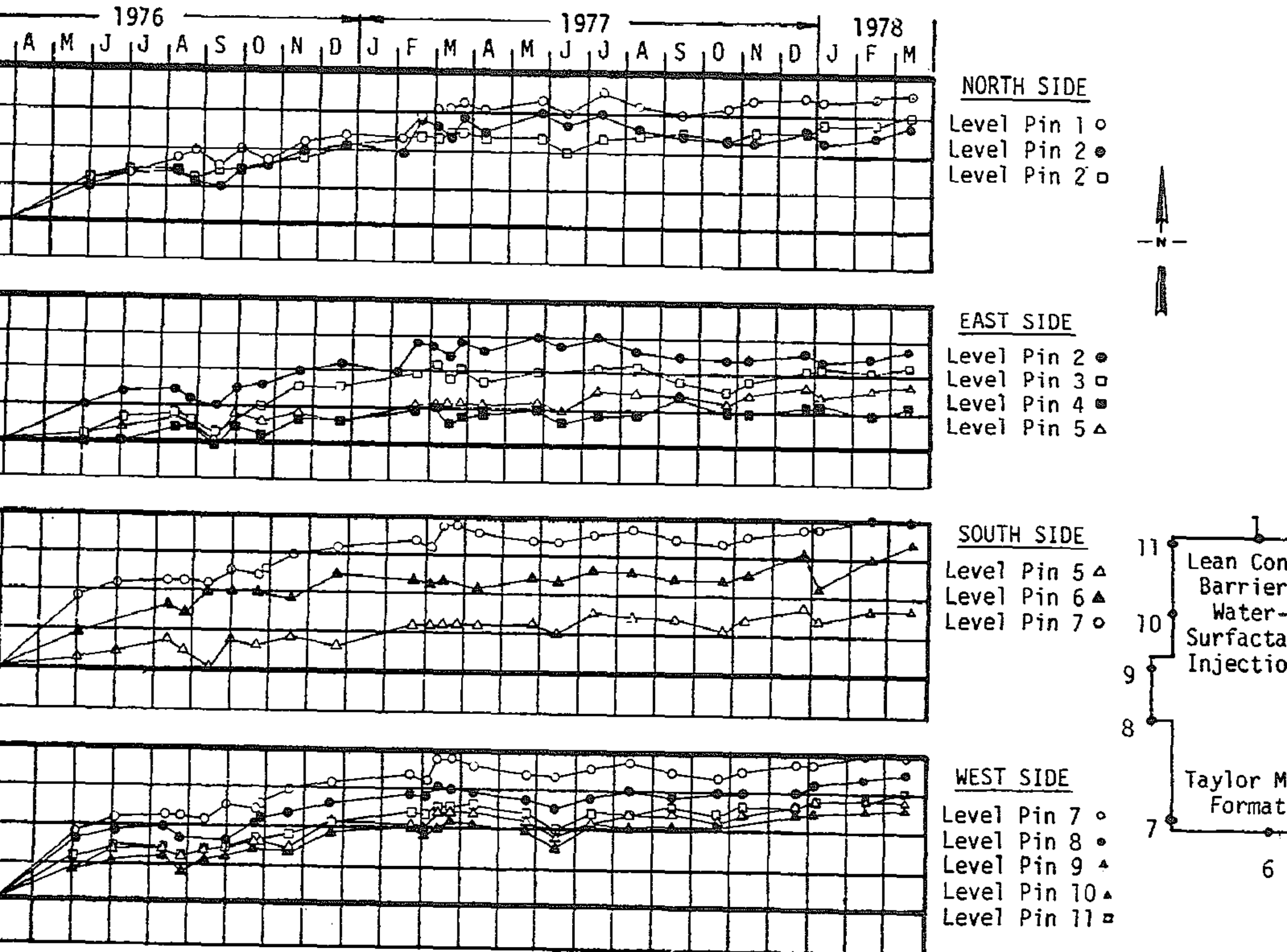
The maximum vertical movement for the test house at 1137 Eastwood Dr Lewisville, Texas, is more than double the vertical movements of the test house at 4204 Culmer, Balch Springs, Texas. These data are for January 1 The same statement is made for absolute differential movements. A compar of the data given in Figures 38, 39, 40, and 41, pages 83, 84, 8 and 87 justify these statements.

Figure 42 and Tables 23 and 24 were developed by taking the high ar low points around the perimeter of each test house and varying these data


NORTH SIDE
Level Pin 1 ○
Level Pin 2 ●
Level Pin 3 △
Level Pin 4 ▲
EAST SIDE
Level Pin 4 ▲
Level Pin 5 □
Level Pin 6 ○
Level Pin 7 ●
Level Pin 8 △
SOUTH SIDE
Level Pin 8 △
Level Pin 9 ▲
Level Pin 10 ○
Level Pin 11 ●
WEST SIDE
Level Pin 11 ●
Level Pin 12 △
Level Pin 13 □
Level Pin 14 ▲
Level Pin 1 ○
1
2
3
4
5
6
13
14
Lean
Concrete
Barrier-
Water
Surfactant
Injection


1976
1977
1978
F M A M J J A S O N D J F M A M J J A S O N D J F M
North Side
East Side
South Side
West Side
1.5
1.0
0.5
0
Change in Elevation (inches)
Lean Concrete Barrier - Water Surfactant Injection
Eagle Ford Formation
1
2
3
4
5
6
7
12
13
14

[illegible]	.152	[illegible]	.033	.396	1.006	.056	.672	1.707	.048	.576	1.463
013	.156	.396	.024	.288	.732	.043	.516	1.311	.038	.456	1.158
020	.240	.610	.026	.312	.792	.031	.372	.945	.027	.324	.823
026	.312	.792	.025	.300	.762	.031	.372	.945	.032	.384	.975
022	.264	.671	.028	.336	.853	.029	.348	.884	.035	.420	1.067
030	.360	.914	.046	.552	1.402	.037	.444	1.128	.023	.276	.701
28	.336	.863	.031	.372	.945	.036	.432	1.097	.024	.288	.732
33	.396	1.006	.033	.396	1.006	.027	.324	.823	.038	.456	1.158
27	.324	.823	.030	.360	.914	.031	.372	.945	.033	.396	1.006
24	.288	.732	.036	.432	1.097	.037	.444	1.128	.043	.516	1.311
28	.336	.853	.041	.492	1.250	.065	.780	1.981	.069	.828	2.103
30	.360	.914	.050	.600	1.524	.050	.600	1.524	.060	.720	1.829
32	.384	.975	.041	.492	1.250	.062	.744	1.890	.079	.948	2.408
19	.228	.579	.044	.520	1.321	.070	.840	2.134	.079	.948	2.408
33	.396	1.006	.049	.588	1.494	.085	1.020	2.591	.092	1.104	2.804
38	.456	1.158	.060	.720	1.829	.083	.996	2.530	.101	1.212	3.078
42	.504	1.280	.057	.684	1.737	.092	1.104	2.804	.115	1.380	3.505
43	.516	1.311	.058	.696	1.768	.095	1.140	2.896	.114	1.360	3.454
51	.612	1.554	.059	.708	1.798	.092	1.104	2.804	.116	1.392	3.536
55	.660	1.676	.065	.780	1.981	.102	1.224	3.109	.130	1.560	3.962
65	.780	1.981	.054	.648	1.646	.111	1.332	3.383	.145	1.740	4.420
53	.636	1.615	.030	.360	.914	.120	1.440	3.658	.141	1.692	4.298
43	.516	1.311	.028	.336	.853	.116	1.392	3.536	.149	1.788	4.542
26	.312	.792	.048	.576	1.463	.099	1.188	3.018	.144	1.728	4.389
43	.516	1.311	.030	.360	.914	.111	1.332	3.383	.129	1.548	3.932



1976
1977
1978
A M J J A S O N D J F M A M J J A S O N D J F M
NORTH SIDE
Level Pin 1 ○
Level Pin 2 ●
Level Pin 2 □
EAST SIDE
Level Pin 2 ●
Level Pin 3 □
Level Pin 4 ■
Level Pin 5 △
SOUTH SIDE
Level Pin 5 △
Level Pin 6 ▲
Level Pin 7 ○
WEST SIDE
Level Pin 7 ○
Level Pin 8 ●
Level Pin 9 ▲
Level Pin 10 ▲
Level Pin 11 ■
N
11
10
9
8
7
6

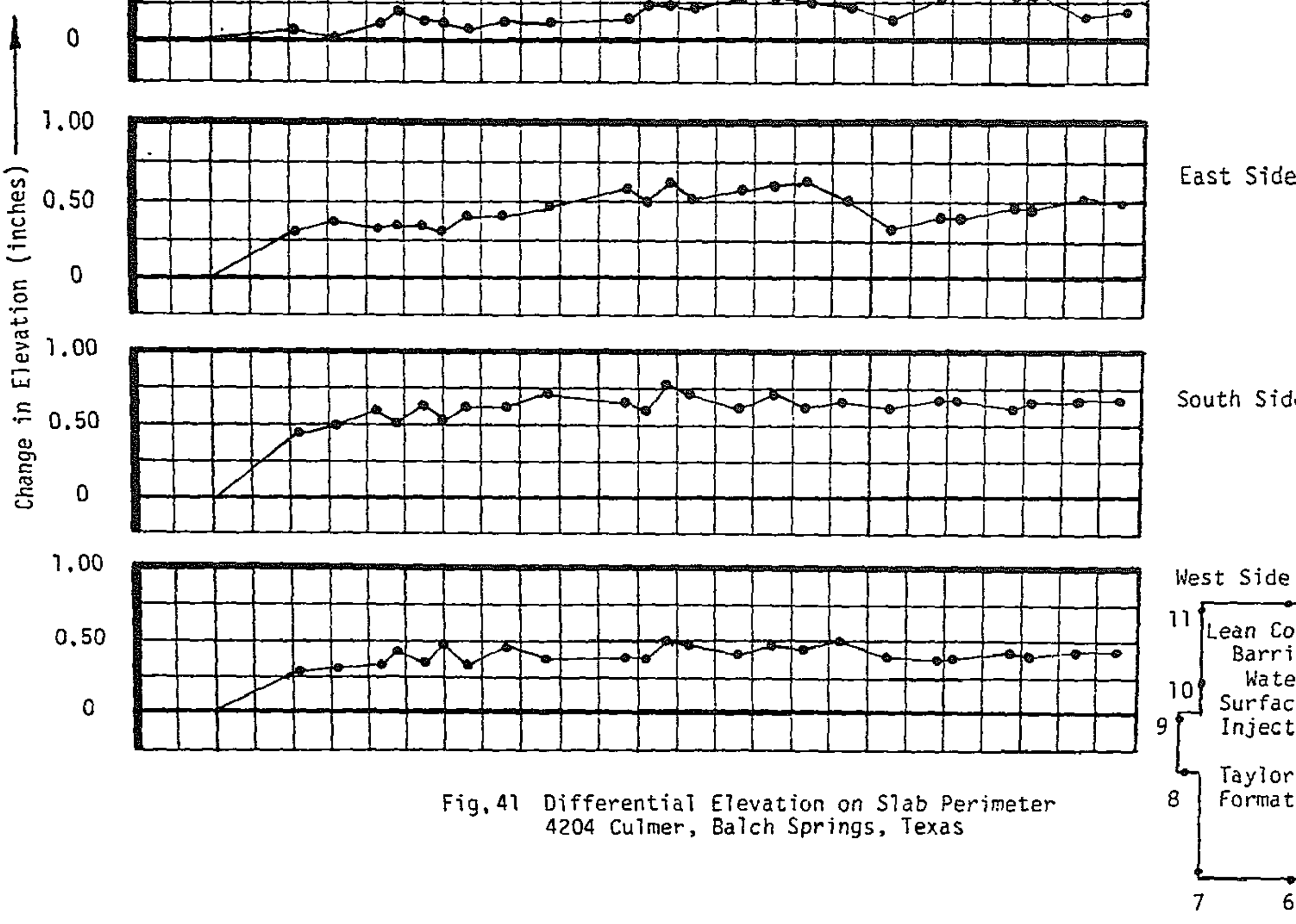


Fig. 41 Differential Elevation on Slab Perimeter
4204 Culmer, Balch Springs, Texas

Table 22

4204 Culmer, Balch Springs, Texas

Differential Elevation: Lot

Date	North Side			East Side			South Side			West Side	
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.
5-02-76	.006	.072	.183	.026	.312	.792	.038	.456	1.158	.023	.276
7-02-76	.002	.024	.061	.034	.408	1.036	.070	.840	2.134	.025	.300
3-13-76	.009	.108	.274	.027	.324	.823	.049	.588	1.494	.027	.324
3-26-76	.018	.216	.549	.029	.348	.884	.043	.516	1.311	.037	.446
9-14-76	.013	.156	.396	.229	.348	.884	.054	.648	1.646	.028	.336
9-30-76	.012	.144	.366	.036	.312	.792	.045	.540	1.372	.041	.492
0-22-76	.007	.084	.213	.035	.420	1.067	.046	.552	1.402	.025	.300
0-26-76	.009	.108	.274	.035	.420	1.067	.052	.624	1.585	.027	.324
1-18-76	.012	.144	.366	.035	.420	1.067	.052	.624	1.585	.037	.444
2-21-76	.010	.120	.305	.040	.480	1.219	.062	.744	1.890	.031	.372
2-22-77	.014	.168	.427	.040	.588	1.494	.056	.672	1.707	.034	.408
3-04-77	.020	.240	.610	.041	.492	1.250	.051	.612	1.554	.033	.396
3-14-77	.017	.204	.518	.047	.564	1.433	.064	.768	1.951	.043	.516
3-25-77	.020	.240	.610	.055	.660	1.676	.065	.780	1.981	.040	.480
4-11-77	.018	.216	.549	.044	.528	1.341	.061	.732	1.859	.039	.468
5-23-77	.024	.288	.732	.049	.588	1.494	.052	.624	1.585	.036	.432
6-14-77	.023	.276	.701	.051	.612	1.554	.061	.732	1.859	.040	.480
7-12-77	.029	.348	.884	.054	.648	1.646	.052	.624	1.585	.037	.444
3-11-77	.019	.228	.579	.044	.528	1.341	.057	.684	1.737	.041	.492
9-15-77	.013	.156	.396	.028	.336	.853	.052	.624	1.585	.034	.408
0-21-77	.023	.276	.701	.034	.408	1.036	.056	.672	1.707	.032	.384
1-11-77	.029	.348	.884	.033	.396	1.006	.055	.660	1.676	.033	.396
2-20-77	.023	.276	.701	.038	.456	1.158	.051	.612	1.554	.035	.420
1-05-78	.026	.312	.792	.032	.384	.975	.059	.708	1.798	.034	.408
2-13-78	.017	.204	.518	.044	.528	1.341	.059	.708	1.798	.038	.456
3-10-78	.020	.240	.610	.041	.492	1.250	.059	.708	1.798	.038	.456

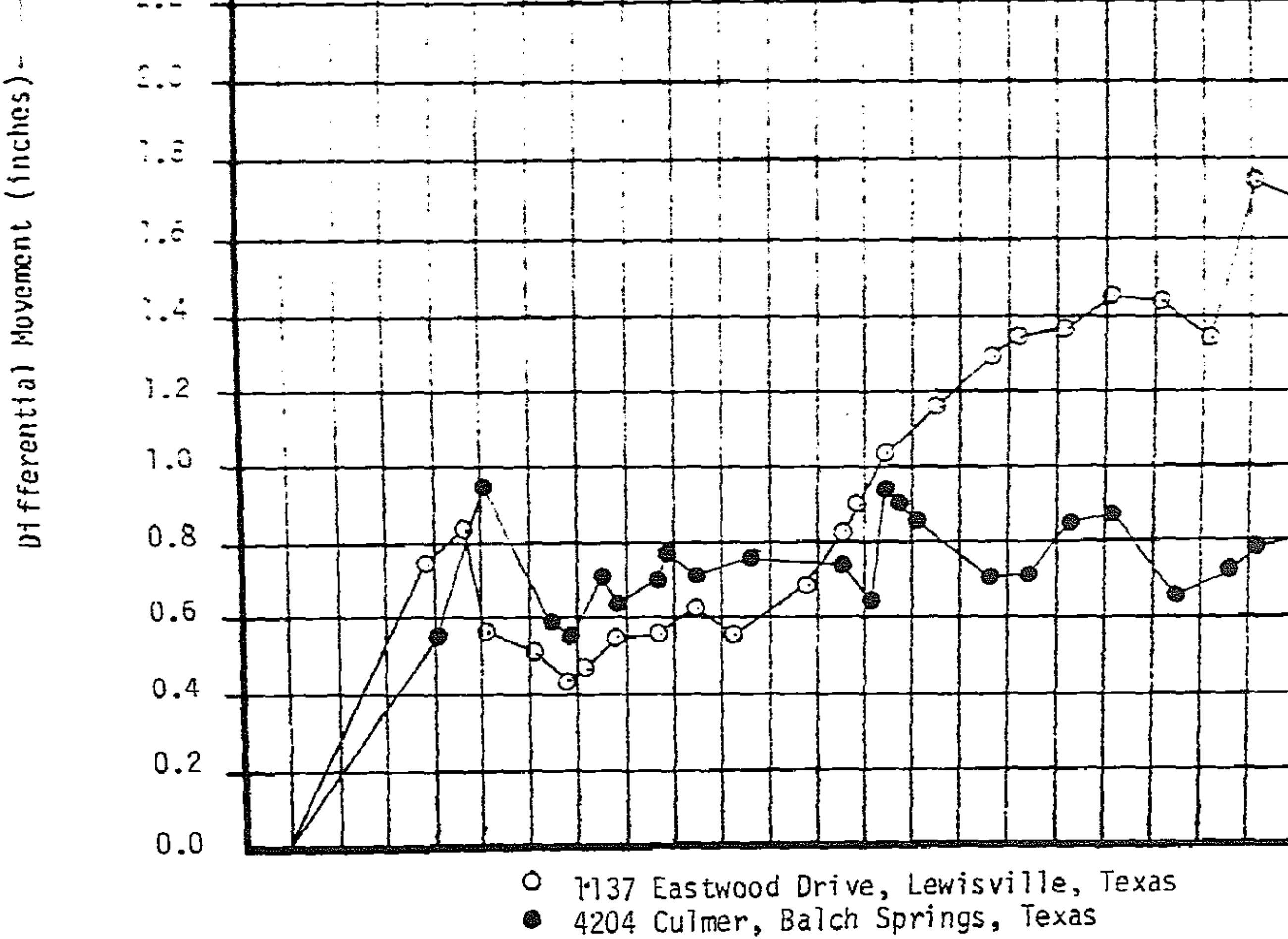


Fig. 42 Maximum Perimeter Differential Movement Comparison of Co
Barrier on Different Geologic Formations.

Maximum Perimeter Differential Movement

Date	Movement		
	Feet	Inches	
May 25, 1976	.062	.744	1.
June 21, 1976	.068	.816	2.
July 9, 1976	.048	.576	1.
Aug. 9, 1976	.040	.480	1.
Aug. 23, 1976	.036	.432	1.
Sep. 9, 1976	.039	.468	1.
Sep. 29, 1976	.046	.552	1.
Oct. 21, 1976	.046	.552	1.
Nov. 16, 1976	.051	.612	1.
Dec. 9, 1976	.046	.552	1.
Jan. 27, 1977	.057	.684	1.
Feb. 18, 1977	.069	.828	2.
Feb. 28, 1977	.076	.912	2.
Mar. 14, 1977	.086	1.032	2.
Apr. 19, 1977	.098	1.176	2.
May 24, 1977	.107	1.284	3.
June 10, 1977	.114	1.368	3.
July 8, 1977	.115	1.380	3.
Aug. 5, 1977	.121	1.452	3.
Sep. 7, 1977	.119	1.428	3.
Oct.10, 1977	.112	1.344	3.
Nov. 2, 1977	.145	1.740	4.
Dec. 1, 1977	.141	1.691	4.
Jan. 4, 1978	.149	1.7881	4.
Feb. 6, 1978	.147	1.764	4.
Mar. 8, 1978	.132	1.584	4.
Apr. 3, 1978	.14	1.68	4.
May 15, 1978	.147	1.764	4.

Date	Movement		
	Feet	Inches	Cm.
2, 1976	.045	.540	1.372
y 2, 1976	.079	.948	2.408
. 13, 1976	.049	.588	1.494
. 26, 1976	.047	.564	1.433
. 14, 1976	.059	.708	1.798
. 30, 1976	.052	.624	1.585
. 22, 1976	.057	.684	1.737
. 26, 1976	.062	.744	1.890
. 18, 1976	.058	.696	1.768
. 21, 1976	.063	.756	1.920
. 7, 1977	-	-	-
. 22, 1977	.061	.732	1.859
. 4, 1977	.052	.624	1.585
. 14, 1977	.078	.936	2.377
. 25, 1977	.076	.912	2.316
. 11, 1977	.070	.840	2.134
23, 1977	.058	.696	1.768
e 14, 1977	.059	.708	1.798
y 12, 1977	.070	.840	2.134
. 11, 1977	.071	.852	2.164
. 15, 1977	.053	.636	1.615
. 21, 1977	.060	.720	1.829
. 11, 1977	.066	.792	2.012
. 20, 1977	.067	.804	2.042
. 5, 1977	.069	.828	2.103
. 13, 1978	.077	.924	2.347
. 10, 1978	.074	.888	2.256
. 3, 1978	.079	.948	2.408

In both instances, the subsoil mass was enclosed by a relatively im-
rmeable concrete barrier, inhibiting climatic effects. The data given
dicates activity within the soil mass in adjusting to stability. Sig-
ficant deviation or abrupt changes from a smooth curve was considered an
dication of expansive clay activity. Further, as data points appeared to
approaching or becoming asymptotic to a horizontal plane would indicate
e subsoil mass beneath each test house was reaching relative stability.

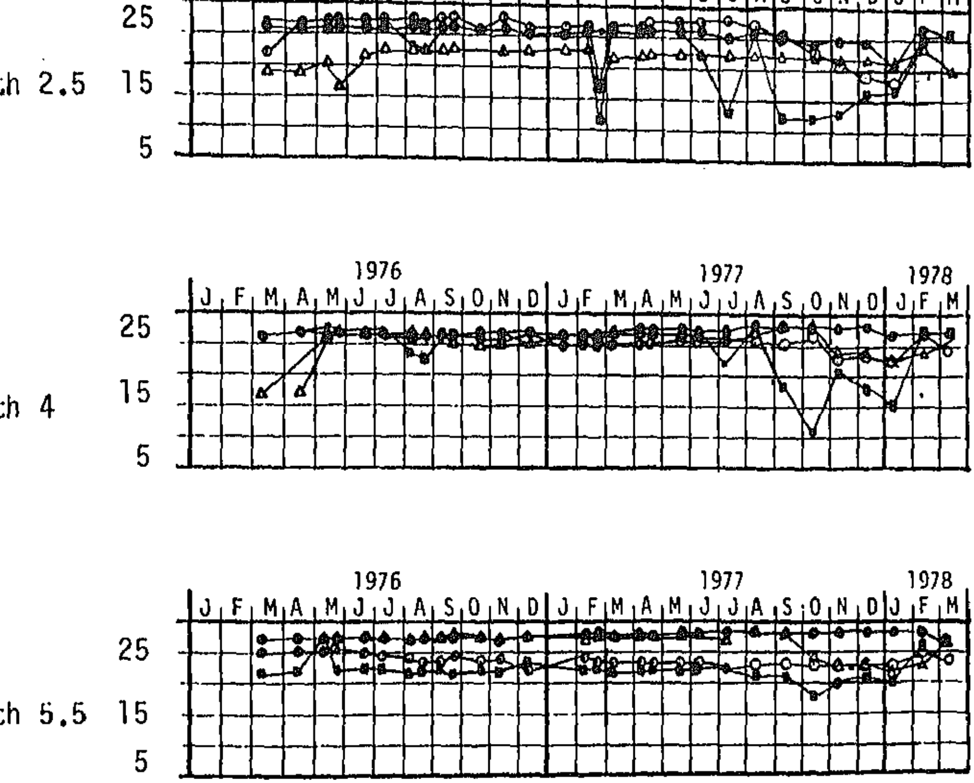
Figure 42 illustrates this concept and shows the soil mass beneath the
st house on the Taylor formation surrounded by a vertical concrete barrie
be approaching relative stability. The test house founded on the Eagle
rd formation is still undergoing significant swelling as indicated by the
ope of the data points.

.4 Soil Moisture-Temperature Characteristics - 1137 Eastwood Drive,
Lewisville, Texas

Data acquisition for variation in soil moisture content with time, as
ven in Figure 43, commenced upon completing all tasks associated with
ilizing the lean concrete barrier as a subsoil stabilization technique.
gnificant variation was noted in moisture contents as a function of time
all depths of interest.

The average Plastic Limit in the upper five feet of the soil at this
st house was 24.75 percent. As indicated by Figure 43, the minimum re-
irement for the soil moisture to be a minimum of 2-3 percent above the
astic Limit was not achieved for certain depths and different sides of
e house. While some reading error is apparent in certain instances, the
isture content as taken from the moisture-temperature cells was not incre
the desired level.

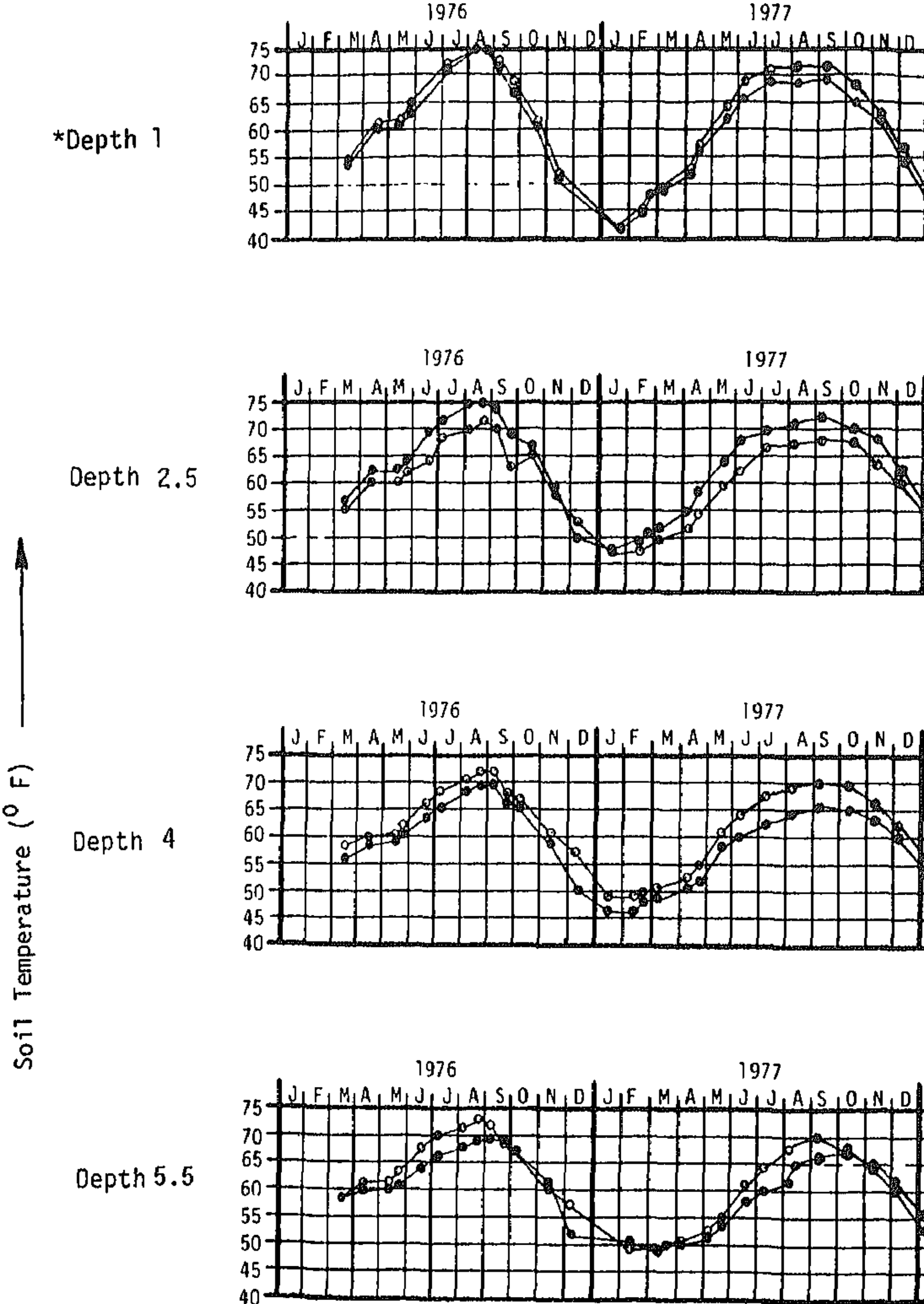
As given in Section 4.4.1, 9,827 gallons of water were added to the su
ils beneath the floor slab and surrounded by the concrete barrier. Furth
e entire volume of water was added to the soil from the interior of the
use. The floor slab had a "cupped" configuration, and borings were made
rough the slab on the interior of the house governed by the high and low
nts determined by topographical survey. Further, testing of the soils i
e upper five feet to determine whether or not the moisture content was
ised to the minimum desired was also accomplished at the access points
om the interior of the house. The moisture-temperature cells are install
borings approximately 12-18 inches from the house perimeter which may
sult in the moisture gradient decreasing and recording less than the opti
the instruments. If the preceding was the case, it is then possible tha
e installed instruments and the insitu soil do not have completely intima
ntact resulting in readings that are less than desirable. The mass of so
closed by the vertical concrete barrier could have different moisture con
nts throughout and particularly have higher moisture contents at the in-



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 43 Soil Moisture Content - Lean Concrete Barrier
1137 Eastwood Drive, Lewisville, Texas



Soil Temperature (° F)
*Depth 1
Depth 2.5
Depth 4
Depth 5.5
1976
1977
J F M A M J J A S O N D J F M A M J J A S O N D
75
70
65
60
55
50
45
40

variation of subsoil temperature with time and for different depths in Figure 44 . These curves exhibit the characteristic sine wave hout any significant lag time from climatic conditions. Figure 44 strates the insulating properties of the soil by the decrease in litude with depth. The temperature means and standard deviations test house are given in Table 25.

Soil Moisture-Temperature Characteristics - 4204 Culmer, Balch Springs, Texas

ation of subsoil moisture characteristics with time for this test the Taylor formation is given in Figure 45 . Data acquisition com- on completing all actions associated with the use of a vertical barrier as a stabilization technique to inhibit moisture migration. test house the moisture content was increased to a minimum of 2-3 bove the average Plastic Limit of the soil, which was approximately ent within the upper five feet. It is apparent that some adjust- was required to raise the soil moisture content from its insitu f 17.3 percent. The maximum variation of the natural water content il below the Plastic Limit was 8.2 percent.

amount of water added to the foundation soil was 13,410 gallons or s the water added to the test house utilizing the same subsoil tion technique and located on the Eagle Ford formation. The charac- dense condition of the subsoils of the Taylor formation and associated racks and fractures caused water to be lost to significant depths th the concrete barrier. As these migration paths were gradually expansion of the soil, the desired moisture content of the soil ved. After initial adjustment, the curves of Figure 45 exhibit ed narrow band width and remain relatively constant with time. This icate climatic effects are not exhibiting significant influence on il moisture.

variation of soil temperature with time and depth is given in Figure ese curves show the characteristic shape without lag time. However, 26, page 96, temperature means and standard deviations indi- noperative thermistor at the 5.5 foot depth on the West side of the onsequently, the North and South side temperatures are averaged, second curve indicates soil temperatures of the East side only for foot depth of interest.

TEMPERATURE MEANS AND STANDARD DEVIATION

1137 Eastwood Drive, Lewisville, TX

Concrete Barrier-Water Surfacant Inection

ll tion	*Depth (ft) 1	2.5	4	5.5
h	58.55 10.53	60.61 8.92	58.68 7.75	59.15 7.18
	59.95 10.02	64.00 8.41	56.56 7.94	57.53 7.19
h	64.58 10.68	60.24 6.97	63.60 7.91	64.10 9.40
	60.53 10.04	62.98 9.13	60.70 7.62	61.10 6.82

TEMPERATURE MEANS AND STANDARD DEV

4204 Culmer, Balch Springs, T

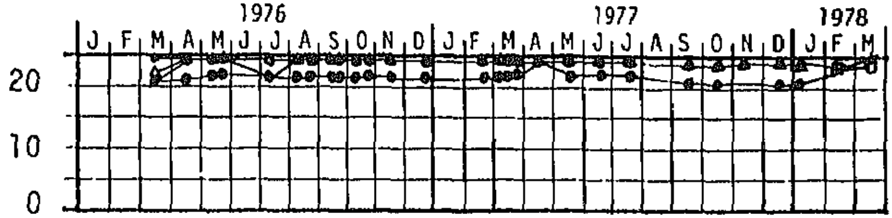
Lean Concrete Barrier-Water Surfacant

Location	*Depth (ft) 1	2.5	4
North	61.33 11.08	59.11 8.24	59.93 9.08
East	60.40 10.28	62.63 9.30	61.20 8.65
South	60.53 10.19	62.95 9.12	56.10 9.31
West	62.18 9.83	63.72 8.72	60.98 8.30

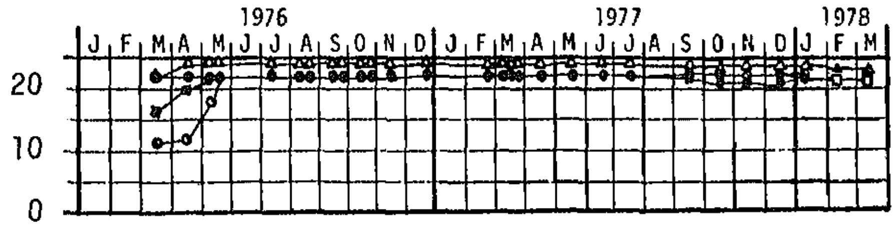
*Depth refers to feet below grade beam.

2.5

4



5.5



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 45 Soil Moisture Content - Lean Concrete
4204 Culmer, Balch Springs, Texas

investigation, natural properties of the foundation subsoil were establis
Among these were the insitu moisture content averaging 13.2 percent five
and a deviation of 8.2 percent maximum below the average Plastic Limit of
24.75 percent.

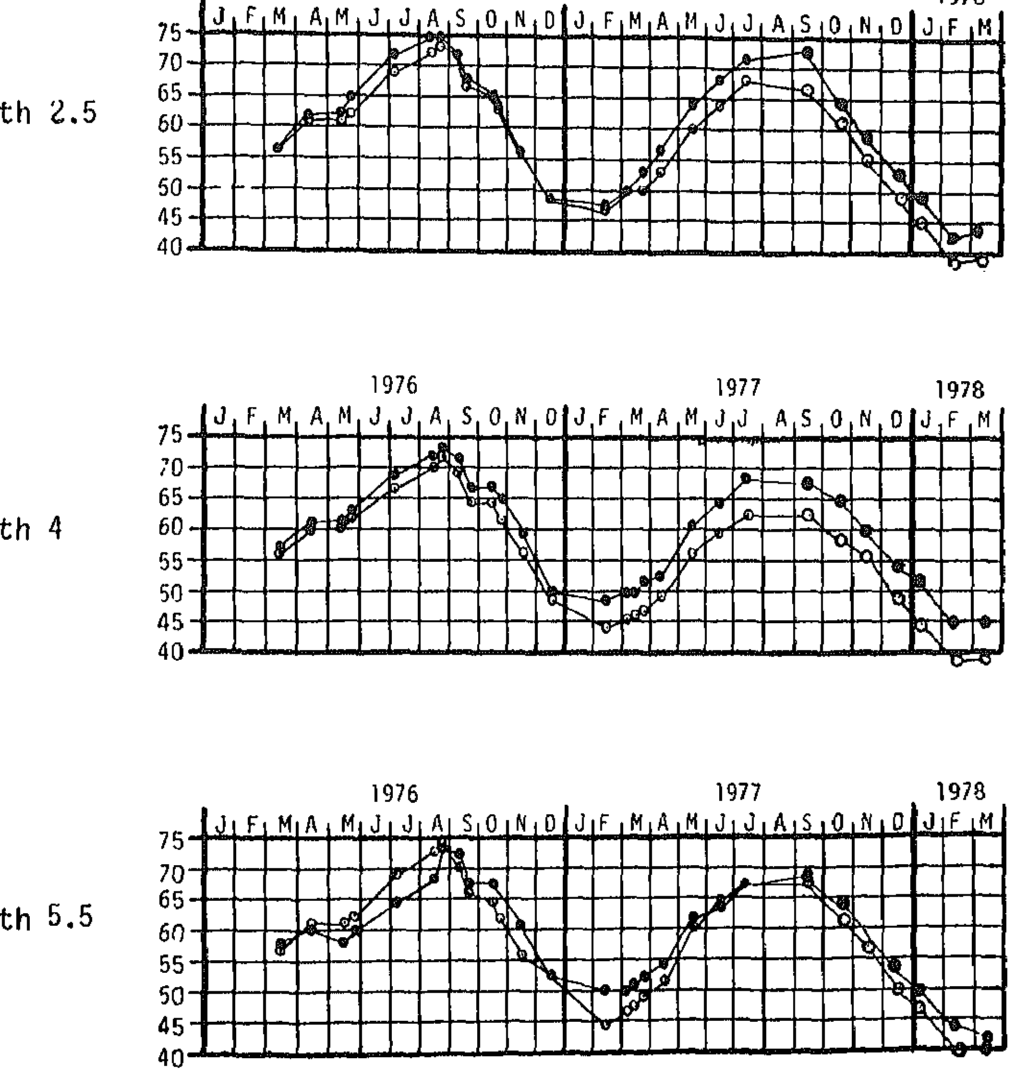
The test house at 4204 Culmer, Balch Springs, Texas, was founded on residual expansive clay soils of the Taylor formation. The soils investi-tion established the natural properties of the subsoil beneath the test house. These included the insitu moisture content averaging 17.3 percent a five foot depth and having a maximum deviation of 8.2 percent below the average Plastic Limit of 20.2 percent. All soils investigations were ac-complished prior to initiating stabilizing actions.

For these two test houses, the average index properties discussed ar relatively close. The average insitu moisture contents being 13.2 and 17 percent respectively and both deviate a maximum of 8.2 percent below the respective average Plastic Limits of 24.75 percent and 20.2 percent. The average properties are to a depth of approximately five feet or the depth of the concrete moisture barrier.

For these two test locations, the amount of Montmorillonite clay minerals within the upper five feet of soil for the house located on the Eagle Ford formation is approximately 12.85 percent. The amount of Mont-morillonite clay for the five feet of soil beneath the test house on the Taylor formation is approximately 39.8 percent. This amounts to a differ of 26.95 percent. This significant percentage of these highly expansive minerals, along with the method of introducing water into the foundation soils may explain the variation in moisture contents at the moisture-temp ture cell locations at the two sites.

It would appear that when water is introduced around the house peri-meter higher moisture contents are reflected on the installed instrumenta Understandably, the moisture migration paths are much less and cracks and fractures provide the primary avenues of travel until swelling precludes further movement. Further moisture migration would then be a function of permeability of the soil if free water still remains available. The amou of free water would be that which could be pulled through the soil capill by forces stronger than the forces of the clay minerals in developing the double layer.

For the test house at 1137 Eastwood Drive, Lewisville, Texas, the act condition of the subsoil beneath the slab interior was largely indetermina However, knowing the slab interior was lower than the perimeter indicated more desiccated condition. Even though, laboratory testing showed the sul soil moisture within the house interior was raised by the addition of wat to the desired value, there was nothing to preclude moisture migrating dow ward as well as laterally. This could reduce the moisture content of the



-Key-

o North and South Side Average
● East and West Side Average

pths refer to feet below grade beam.

. 46 Soil Temperature Variation
4204 Culmer, Balch Springs, Texas

il beneath the house as a much larger volume of soil would be included. nally, movement of water laterally to the instrumentation points could ve been restricted to a degree by the natural soil forces, and equilibri tablished with different moisture contents. As the house perimeter was gher than the interior, it follows the moisture content was also higher. nsequently, the soil moisture demand would be less at the perimeter, and e forces inherent in satisfying this demand, for moisture migration from drier environment to a more moist regime would also be less.

A comparison of soil temperature variation with time from data given Figures 44 and 46, and Tables 25 and 26, pages 94, 99, and 96 e relatively similar. Any significant variation is considered due to ss of instrumentation. Figures 44 and 46 both show the same basic chara tics without significant lag time. This would infer that temperature fects within the soil vary too rapidly to greatly effect moisture conten en enclosed by a barrier. Temperature data do indicate the effectivenes soil as an insulating medium.

5 EVALUATION OF VERTICAL MOISTURE MIGRATION BARRIERS

The primary purpose of the three different types of vertical moisture gration barriers was to inhibit or minimize vertical movement of the fou on subsoil. The mechanism of accomplishment was to cut the soil capilla thin the mass at the interface of soil and vertical barriers. This woul nimize moisture loss and subsequent volume fluctuations caused by climat fluence. This condition would be effected in approximately five feet of bsoil below the floor slab, causing the house structure, floor slab, and bsoil to behave as a layered system. This soil-structure interaction wo splace the plane of reference for vertical movements or volume change so ve feet beneath the bottom of the floor slab. Any vertical movement wou en be inhibited by the unit loading of the structure on the soil surface us the significant weight of five feet of soil over a unit area.

In evaluating the relative effectiveness of the three types of vertic isture migration barriers on two different geologic formations, a review l figures associated with vertical movements and differential elevations ong each side of the individual test houses reveals certain conditions ist.

The magnitude of vertical movements was not unexpected due to the dam ndition of the test houses and the volume of water required for increasi bsoil moisture to the desired level. Maximum differential elevation cha uld also be initially large for same reasons. Both the Eagle Ford and ylor formations were sedimentary in nature and consequently had a wide r soil particle types. Their plastic behavior, however, would classify t sidual soils, on both formations, as inorganic clays of high plasticity

he deposition process. If these clay minerals occur in pockets,
re available at one point and not another, within the subsoils
st house, differential movements would be increased.

enerally accepted the Taylor formation would be the more active
ologic units due to the high percentage of Montmorillonite
within the upper five feet of soil and to significant depths.
ng installation of the vertical barriers it was observed that
erials contained varying amounts of fine sand and silt which
the clay behavior to a significant degree. After water was
l and differential movements would initially increase, however,
r would disperse more rapidly with time resulting in decreased
soil moisture became more uniform. Consequently, it may be
ted that the vertical barriers on the Taylor formation resulted
formance than those on the Eagle Ford formation.

e Figures 20, 22, 29, 31, 38, and 40, pages 44, 48,
and 86. Relative uniformity of magnitude of vertical movement
s of reference around the house perimeter was observed. This
ficant variable as abrupt changes in short spans result in
tios that are untenable for concrete slabs and brick veneer

e Figures 20, 23, 30, 32, 39, and 41, pages 44, 49, 64,
nd 87. A comparison of these curves with time generally indi-
ncy towards stability or becoming asymptotic to a horizontal
is especially true for contigous sides of the house.

e Figures 24, 33, and 42, pages 52, 70, and 89. These
trate performances of the same stabilizing technique in the two
ations. Again, these are absolute values, but indicate the
vity of the subsoils beneath the test houses on the two formations.

mance summary combining six test houses, three stabilizing
nd two formations is given in Table 27. In all instances, the
iers on the Taylor formation indicate better performance in
mum perimeter differential movement. It was also concluded that
es were viable procedures for stabilizing foundation subsoils.
y be determined from economic consideration.

ated in Section 4.1, a trenching or excavating machine is now
mercially which can dig the narrow vertical barrier trench
djacent to the perimeter of a house. Further, as the excavating
be offset to either side of the machine, changes in direction
figurations would not be the problem they were in this study.
esult in cost savings in excavation, labor and materials for the
neal foot associated with this research.

In using a capillary barrier, a homeowner may further reduce costs b ersonally performing part of the work. This would require having the tr ng accomplished by others, ordering the computer quantity of barrier mat nd then placing the material and removing spoil, from the excavation pro ith his own resources. Naturally, this would involve considerable labor ut is entirely feasible if cost is a paramount consideration.

In using a rubber barrier, certain costs could be reduced as mention reviously. However, these could be offset by other factors. Rubber aterials utilized in this study were waste products from tire recapping perations. Costs were minimal for delivering these materials to specifi ocations over what the cost was to haul to a disposal site. If this tec ique was adopted to a significant extent, recapping plants would not be dequate source of supply. It is envisioned that a chopping plant for was ire carcasses would be established if sufficient demand or market existe local or regional areas. The output of the plant must provide adequat ize distribution of particles to insure minimum void volume. The mixtur omposition used in this study was not considered the only one which coul e developed, and further study may show it entirely possible to develop ix which would not require expensive, emulsified asphalt and still achie elative impermeability.

In using a lean concrete barrier costs would again be reduced from hose indicated in Table 27 , page . As relative impermeability, ather than strength, was the essential criterion, cement quantity service rimarily as a binder to insure sufficient fines within the mix. Extender uch as flyash, which is becoming available in greater quantities as more ignite generating stations are being placed in operation, could be utili part as fines to offset the increased cost of Portland cement. The in- tallation of a concrete barrier could be accomplished in less time than ther two types. By utilizing a high slump concrete (8 inch) the mixture ould flow from a delivery truck with extended chute completely around the xcavation for a vertical barrier. Hand placement is only required where he barrier is not continuous, such as driveways, patios and sidewalk sla

VERTICAL MOISTURE BARRIER
PERFORMANCE SUMMARY
(January 1978)

Test House Address	Formation	Maximum Vertical Movement (inches)				Maximum Differential Movement (inches)				Maximum Perimeter Differential Movement (inches)
		North	East	South	West	North	East	South	West	
1642 Cedar Keys Dr Lewisville, Tx	EF	2.28	3.00	3.00	1.68	0.58	0.77	2.64	1.37	2.64
9909 Bluffcreek Dallas, Tx	T	3.60	3.24	3.72	3.48	0.44	0.19	1.31	0.66	1.45
461 Sweetbriar Dr Dallas, Tx	EF	2.64	2.84	2.28	1.44	1.15	0.66	0.95	0.14	1.64
1314 Athens St Mesquite, Tx	T	1.32	0.84	0.96	1.32	1.16	0.63	0.74	1.16	1.16
1137 Eastwood Dr Lewisville, Tx	EF	1.80	1.80	2.52	2.52	0.52	0.34	1.39	1.78	1.78
4204 Culmer Balch Springs Tx	T	0.84	0.72	1.14	1.14	0.36	0.38	0.71	0.41	0.83

EF - Eagle Ford Formation
T - Taylor Formation

SUBSURFACE IRRIGATION SYSTEMS

5.1 GENERAL

Subsurface irrigation systems were installed under two (2) houses in order to study their suitability as a remedial measure for minimizing differential soil movement. One house is located on soils of each geologic formation under study. These systems have been utilized to continuously provide moisture to subgrades and vegetation for the purpose of stabilizing soil water contents. Once subgrade moisture contents were brought to the optimum, the available moisture should minimize further movement of the structure.

The subsurface irrigation system consisted of a continuous length of porous rubber pipe placed 6 to 8 inches below and in line with the outside edge of all perimeter foundation grade beams. The pipe was manufactured various rates of permeability. Piping materials consisted of recycled rubber tires and recycled plastic. The pipe loop was fed from a pressure regulator placed at the water main to each house and adjusted to supply approximately one gallon per minute to the subgrade under a pressure about six (6) pounds per square inch.

As the installation of each system was complete, flow was started via the porous pipe into the relatively dry subgrades. The flow rates, as expected, were high at first and as the subsoil satisfied its moisture demand, the flow was reduced. Initially, water content of the soil adjacent to the pipe was brought up to optimum. Then, migration of moisture to dry subgrade areas occurred creating a demand for additional flow. This caused water to leak from the porous pipe. The process of gradual wetting of subgrade areas was dependent on soil properties to pull water from the pipe. At equilibrium, the system should automatically provide water to the subs as needed.

5.2 INSTALLATION

The first house around which a subsurface irrigation system was installed was located at 5807 Fess Street, in Dallas, Texas, and was founded on soils belonging to the Eagle Ford geologic formation. The other house where the system was placed in the subgrade was located at 5313 Heath Street, Mesquite, Texas, in an area underlain by the Taylor geologic formation. Details of floor plan of each house, installation procedure, instrumentation, bench developing points costs, and soils investigation have previously been given. Further, contour maps of each floor slab, prices and subsequent to installation of the stabilization technique have also been reported.[1,2]

...differential elevation is 0.66 inches.

As given in Figure 48 and Table 28, the maximum differential moveme... along any side of the house is 0.5 inches for January 1978. The climatic effects are also apparent with time for the approximate 2 year period or ... seasonal cycles associated with this technique.

The data shown in Figures 47 and 48 is even more remarkable when the problems associated with this technique were considered. This test house ... vandalized on more than one occasion, water service shut off for indetermi... periods and the meter removed or stolen.

...2.2 Vertical Movement - 3513 Heath Street, Mesquite, Texas

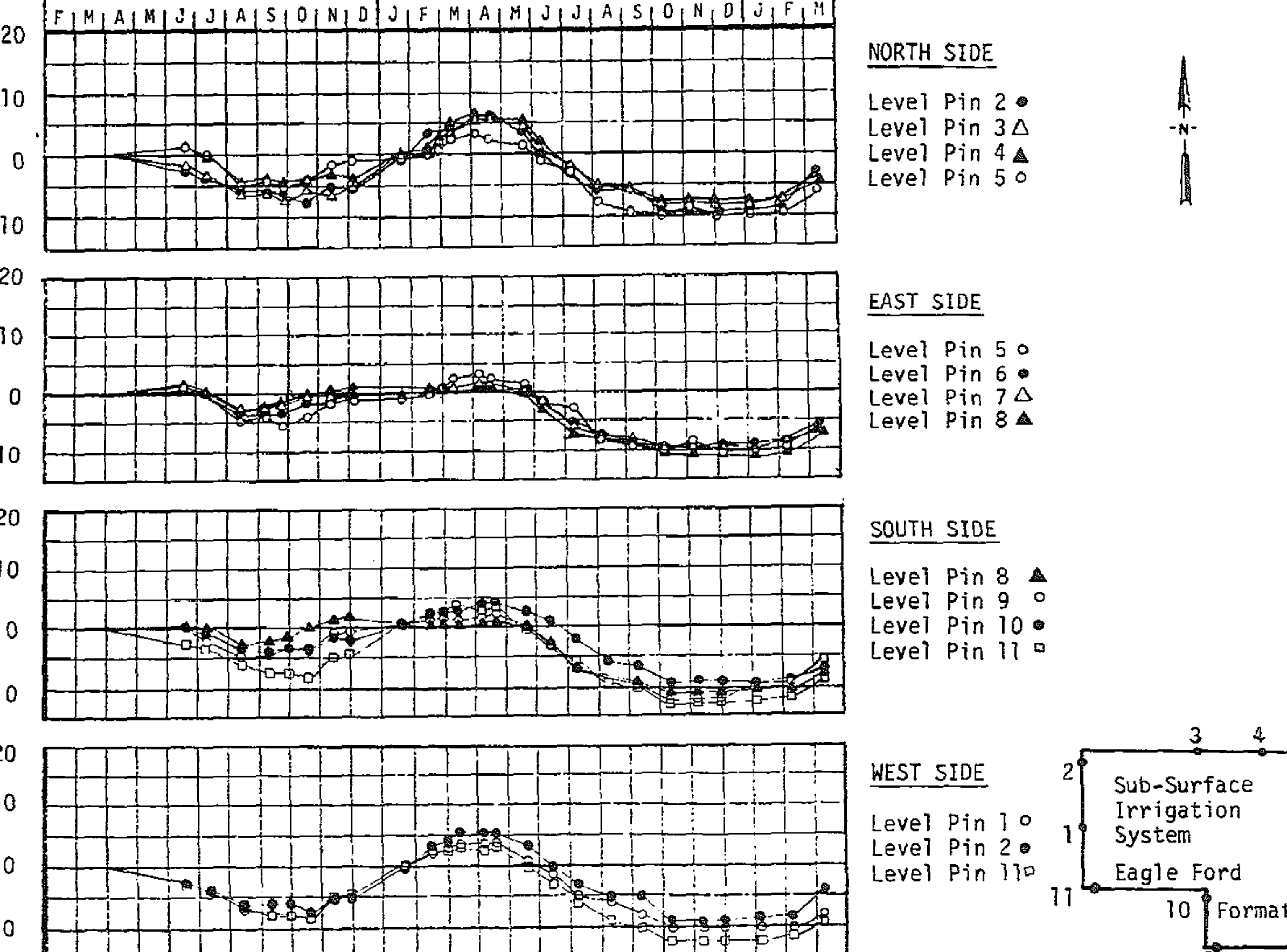
Vertical movements associated with the SIS at 3513 Heath Street, Mesq... Texas, are given in Figure 49 . These data are given for information only because the system was destroyed by the buyer who purchased the property f... ...U.D. Dallas area office.

Again, vertical movements with time show a distinct correlation with climatic cycles. It is evident from Figure 49 when the system ceased to function, or June 1977. Vertical movements were approximately double for this house as compared to the vertical movements associated with the test house on the Eagle Ford formation.

Differential elevations along each side of the house perimeter are given in Figure 50 and Table 29. Again this information provides a data base for two years or four seasonal cycles; however, it is not a factual indication of system performance.

...2.3 Comparison of Vertical Movements

Comparison of the two test houses on two geologic formations is only ...ible during the period of time both systems are functioning. For this period, the SIS performed remarkable well on the Eagle Ford with vertical movements being approximately one half of the vertical movements for the house on the Taylor formation. Figure 51 and Tables 30 and 31 show abso... values of movement around the perimeter of the house. The data for the house at 5807 Fess Street, Dallas, Texas is factual. The data given for ...



F M A M J J A S O N D J F M A M J J A S O N D J F M
20
10
0
10
NORTH SIDE
Level Pin 2
Level Pin 3
Level Pin 4
Level Pin 5
-N-
EAST SIDE
Level Pin 5
Level Pin 6
Level Pin 7
Level Pin 8
SOUTH SIDE
Level Pin 8
Level Pin 9
Level Pin 10
Level Pin 11
WEST SIDE
Level Pin 1
Level Pin 2
Level Pin 11
Sub-Surface
Irrigation
System
Eagle Ford
Format

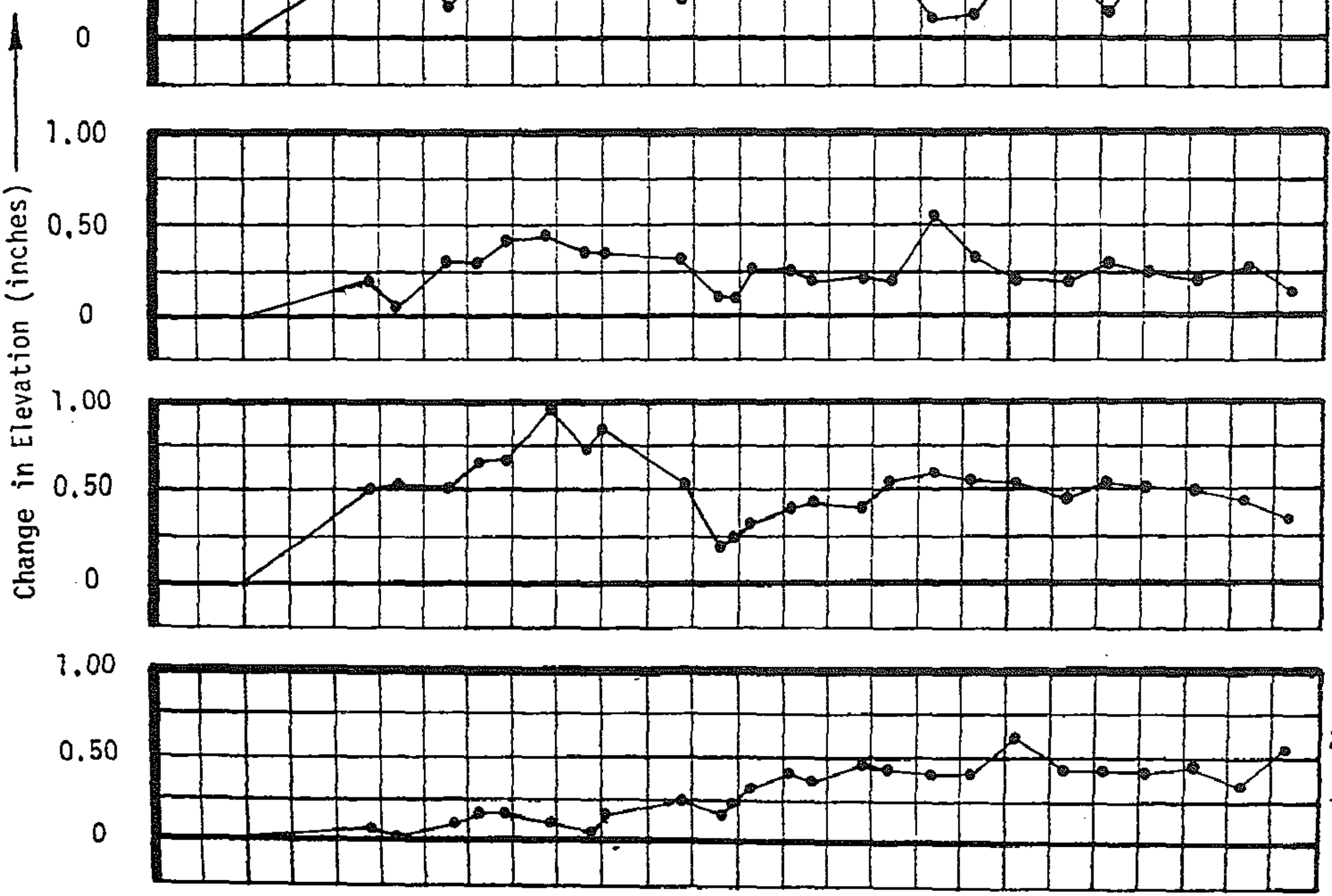
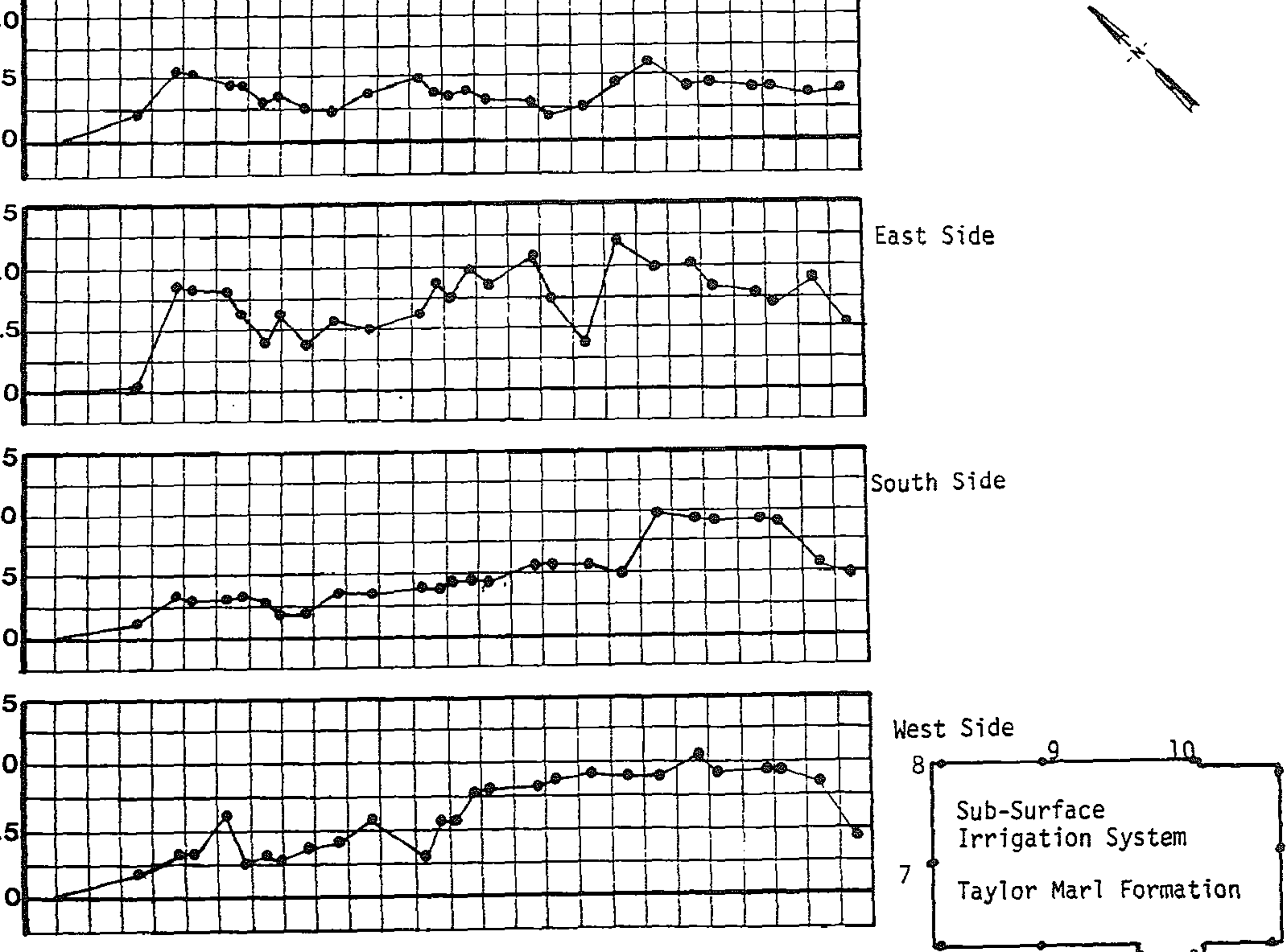


Fig. 48 Differential Elevation on Slab Perimeter
5807 Fess Street, Dallas, Texas

Differential Elevation: Lot

Date	North Side			East Side			South Side			West Side
	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.	In.	Cm.	Ft.
06-23-76	.037	.444	1.128	.016	.192	.488	.041	.492	1.250	.006
07-09-76	.045	.540	1.372	.004	.048	.122	.044	.528	1.341	.002
08-16-76	.017	.204	.518	.024	.288	.732	.042	.504	1.280	.009
09-09-76	.026	.312	.792	.024	.288	.732	.055	.660	1.676	.014
09-29-76	.022	.264	.671	.035	.420	1.067	.056	.672	1.707	.014
10-21-76	.028	.336	.853	.036	.432	1.097	.082	.984	2.499	.008
11-16-76	.042	.504	1.280	.030	.360	.914	.061	.732	1.859	.005
12-02-76	.043	.516	1.311	.029	.348	.884	.071	.852	2.164	.013
01-21-77	.020	.240	.610	.028	.336	.853	.044	.528	1.341	.008
02-18-77	.041	.492	1.250	.010	.120	.305	.018	.216	.549	.014
02-28-77	.037	.444	1.128	.009	.108	.274	.020	.240	.610	.020
03-11-77	.029	.348	.884	.021	.252	.640	.028	.336	.853	.027
04-04-77	.039	.468	1.189	.021	.252	.640	.034	.408	1.036	.032
04-19-77	.034	.408	1.036	.015	.180	.457	.036	.432	1.097	.030
05-24-77	.039	.468	1.189	.017	.204	.518	.034	.408	1.036	.040
06-10-77	.036	.432	1.097	.016	.192	.488	.045	.540	1.372	.035
07-08-77	.011	.132	.335	.045	.540	1.372	.050	.600	1.524	.038
08-05-77	.015	.180	.457	.027	.324	.823	.047	.564	1.433	.035
09-07-77	.039	.468	1.189	.017	.204	.518	.044	.528	1.341	.053
10-10-77	.029	.348	.884	.017	.204	.518	.037	.444	1.128	.038
11-04-77	.014	.168	.427	.025	.300	.762	.044	.528	1.341	.036
12-01-77	.036	.432	1.097	.021	.252	.640	.043	.516	1.311	.035
01-04-78	.029	.348	.884	.019	.228	.579	.041	.492	1.250	.037
02-06-78	.026	.312	.792	.022	.264	.671	.040	.480	1.219	.031
03-08-78	.022	.264	.671	.011	.132	.335	.030	.360	.914	.046



East Side
South Side
West Side
8
9
10
7
Sub-Surface
Irrigation System
Taylor Marl Formation

07-76	.049	.528	1.341	.071	.852	2.164						
11-76	.031	.444	1.128	.066	.792	2.012	.026	.312	.792	.052	.624	1.58
26-76	.035	.420	1.067	.054	.648	1.646	.028	.336	.853	.022	.264	.67
14-76	.024	.288	.732	.032	.384	.975	.023	.276	.701	.028	.336	.8
30-76	.028	.336	.853	.049	.588	1.494	.018	.216	.549	.023	.276	.7
22-76	.022	.264	.671	.029	.348	.884	.017	.204	.518	.033	.396	1.0
18-76	.020	.240	.610	.047	.564	1.433	.022	.324	.823	.036	.432	.0
-21-76	.031	.372	.945	.041	.492	1.250	.026	.312	.792	.048	.576	1.4
-07-77	.041	.492	1.250	.055	.660	1.676	.036	.432	1.097	.026	.312	.7
-21-77	.033	.396	1.006	.069	.828	2.103	.033	.396	1.006	.047	.564	1.4
-04-77	.028	.336	.853	.063	.756	1.920	.039	.468	1.189	.049	.588	1.4
-25-77	.032	.384	.975	.081	.972	2.469	.038	.456	1.158	.061	.732	1.8
-11-77	.027	.324	.823	.074	.888	2.256	.037	.444	1.128	.065	.780	1.
-23-77	.024	.288	.731	.093	1.116	2.835	.045	.541	1.372	.068	.816	2.
5-09-77	.015	.180	.457	.063	.756	1.920	.046	.552	1.402	.072	.864	2.
7-11-77	.022	.264	.671	.033	.396	1.006	.047	.564	1.433	.078	.936	2.
3-11-77	.039	.468	1.189	.103	1.236	3.139	.040	.480	1.219	.076	.912	2.
9-15-77	.050	.600	1.524	.081	.972	2.469	.081	.972	2.469	.074	.888	2.
0-27-77	.033	.396	1.006	.087	1.044	2.652	.081	.972	2.469	.090	1.080	2.
1-11-77	.034	.408	1.036	.067	.804	2.042	.075	.900	2.286	.080	.960	2
2-20-77	.028	.336	.853	.062	.744	1.890	.073	.876	2.225	.081	.972	2
1-05-78	.029	.348	.884	.056	.672	1.707	.069	.828	2.103	.081	.972	2
2-13-78	.027	.324	.823	.075	.900	2.286	.048	.576	1.463	.071	.852	2.
3-10-78	.030	.360	.914	.046	.552	1.402	.035	.420	1.067	.039	.468	1

of the test house.

The plot of absolute values for the house on the Taylor formation appeared to be approaching a relative correlation of stability. This can be stated with certainty, but there is no reason to presume otherwise. Figure 51 gives an indication of the activity of the two test houses on two geologic formations and would indicate both data sets are becoming as totic with some pertubations, to a horizontal plane.

5.2.4. Soil Moisture-Temperature Characteristics - 5807 Fess Street, Dallas, Texas

The action of adverse climate is known to initiate soil volume chang with time, and corresponding vertical movement. The subsoil moisture dat as given in Figure 52 vividly show the effects of climate on moisture sta bility in a subsoil. The extreme variation with time on all sides of the house and most depths indicates climatic influence over soil moisture.

For the test house at 5807 Fess Street, Dallas, Texas, a large cotto tree was located in the proximity of the Northeast corner of the house, a the remainder of the yard was barren. The moisture-temperature cells wer installed in borings at the midpoint of each side of the perimeter. A mu wider variation in moisture contents at all depths was observed for the i struments in the North and East side borings. This increased magnitude o variation is not considered due entirely to climate when considering the maining curves. It is believed the root system of the tree is magnifying climatic effects particularly at the lower depths of interest.

Subsoil temperature variations with time and depth are given in Figu These data give an excellent indication of climatic effects on subsoil te perature variation. The curves have the characteristic sine wave shape w out lag time and the curve amplitudes decrease with depth of soil cover. temperature means and standard deviations are given in Table 32.

5.2.5 Soil Moisture-Temperature Characteristics - 3513 Heath Street, Mesquite, Texas

The moisture data given in Figure 54 do not show the extreme variation for this test house as it did for the house on the Eagle Ford f

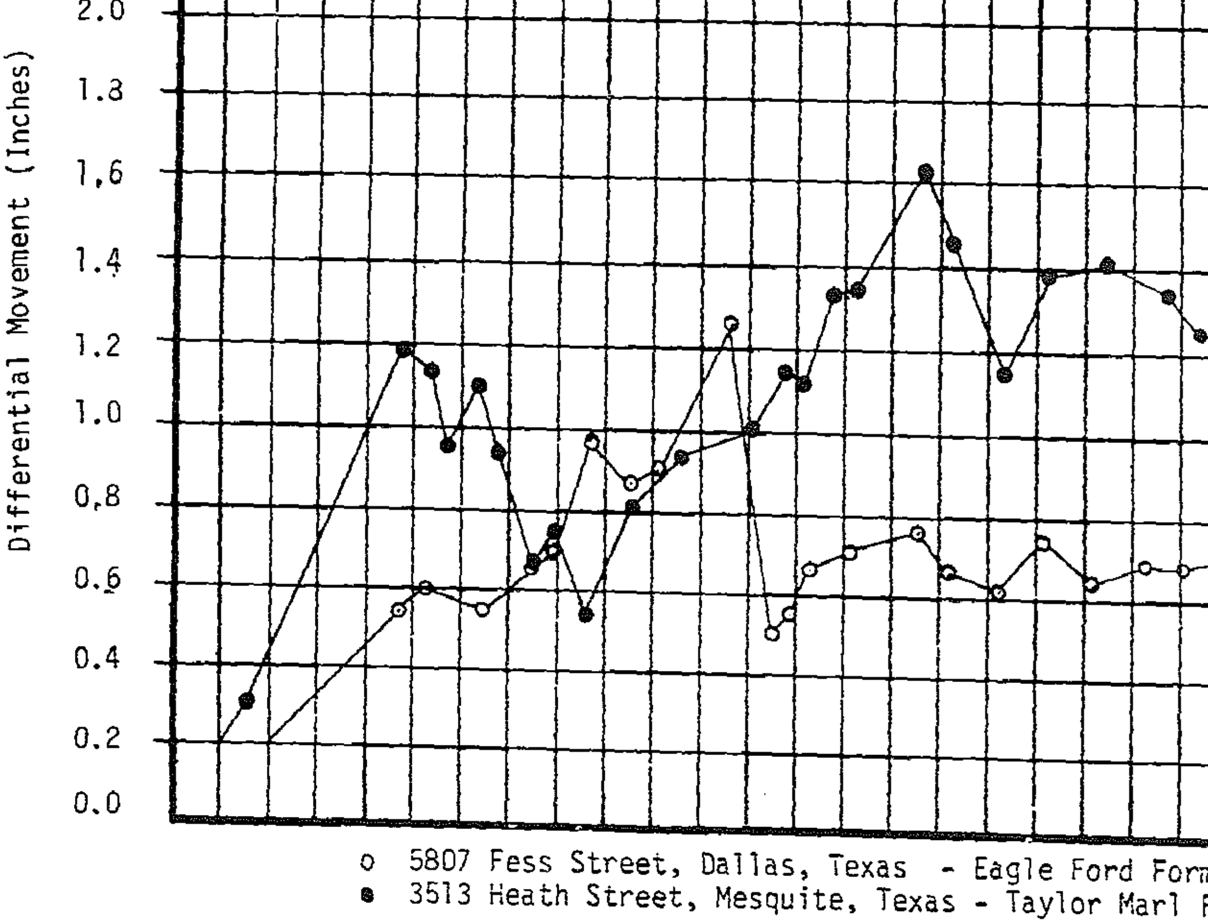


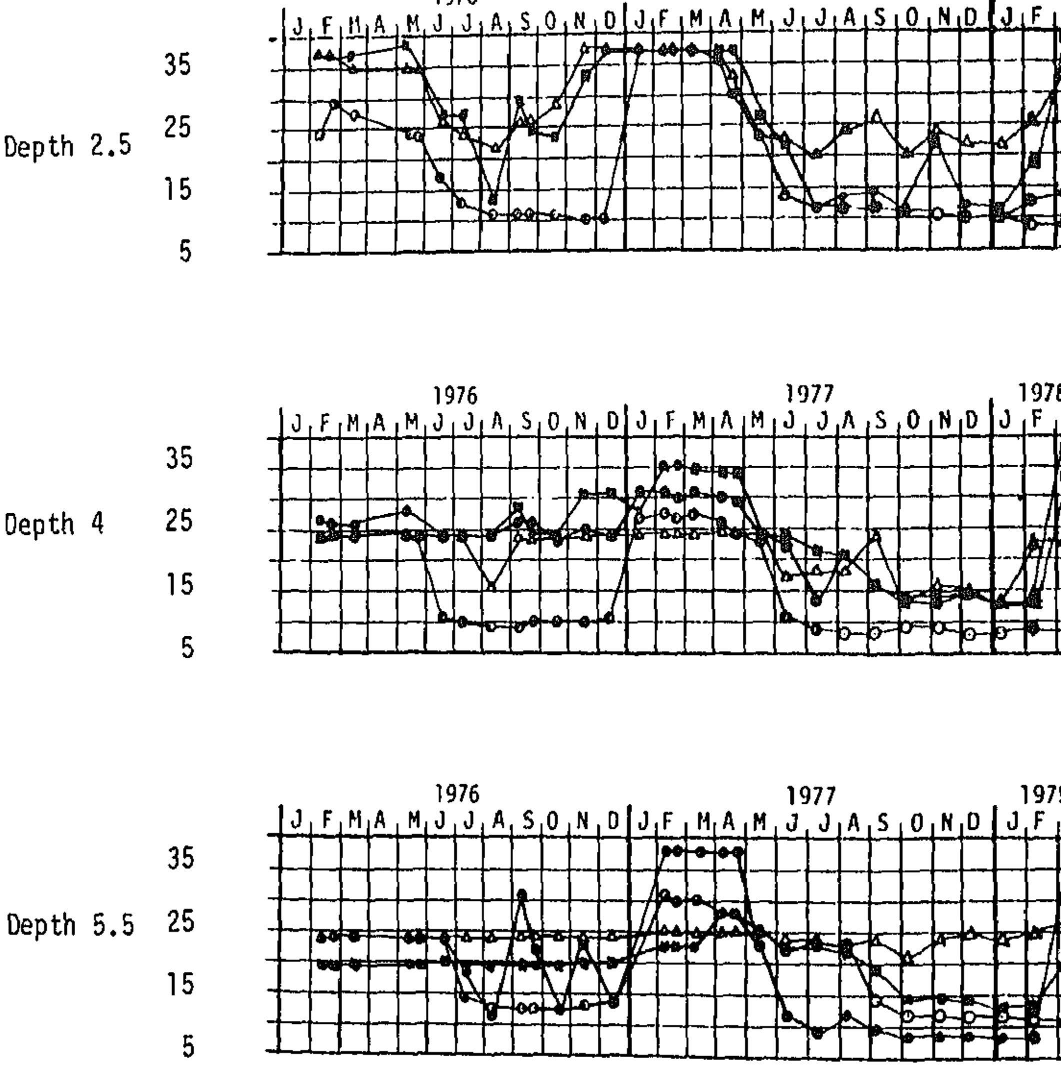
Fig. 51 Maximum Perimeter Differential Movement Comparison on Different Geologic Formations Sub-Surface Irrigation Sys

Date	Movement		
	Feet	Inches	Cm.
June 23, 1976	.047	.564	1.433
July 9, 1976	.050	.600	1.524
Aug. 16, 1976	.046	.552	1.402
Sep. 9, 1976	.055	.660	1.676
Sep. 29, 1976	.059	.708	1.798
Oct. 21, 1976	.082	.984	2.499
Nov. 16, 1976	.072	.864	2.195
Dec. 2, 1976	.074	.888	2.256
Jan. 21, 1977	.104	1.248	3.170
Feb. 18, 1977	.042	.504	1.280
Feb. 28, 1977	.046	.552	1.402
Mar. 11, 1977	.055	.660	1.676
Apr. 4, 1977	.060	.720	1.829
May 24, 1977	.064	.768	1.951
June 10, 1977	.055	.660	1.676
July 8, 1977	.051	.612	1.554
Aug. 5, 1977	.062	.744	1.890
Sep. 7, 1977	.053	.636	1.615
Oct. 10, 1977	.057	.684	1.737
Nov. 4, 1977	.057	.684	1.737
Dec. 1, 1977	.059	.708	1.798
Jan. 4, 1978	.053	.636	1.615
Feb. 6, 1978	.050	.600	1.524
Mar. 8, 1978	.046	.552	1.402

3515 Heath Street, Mesquite, Texas

Maximum Perimeter Differential Movement

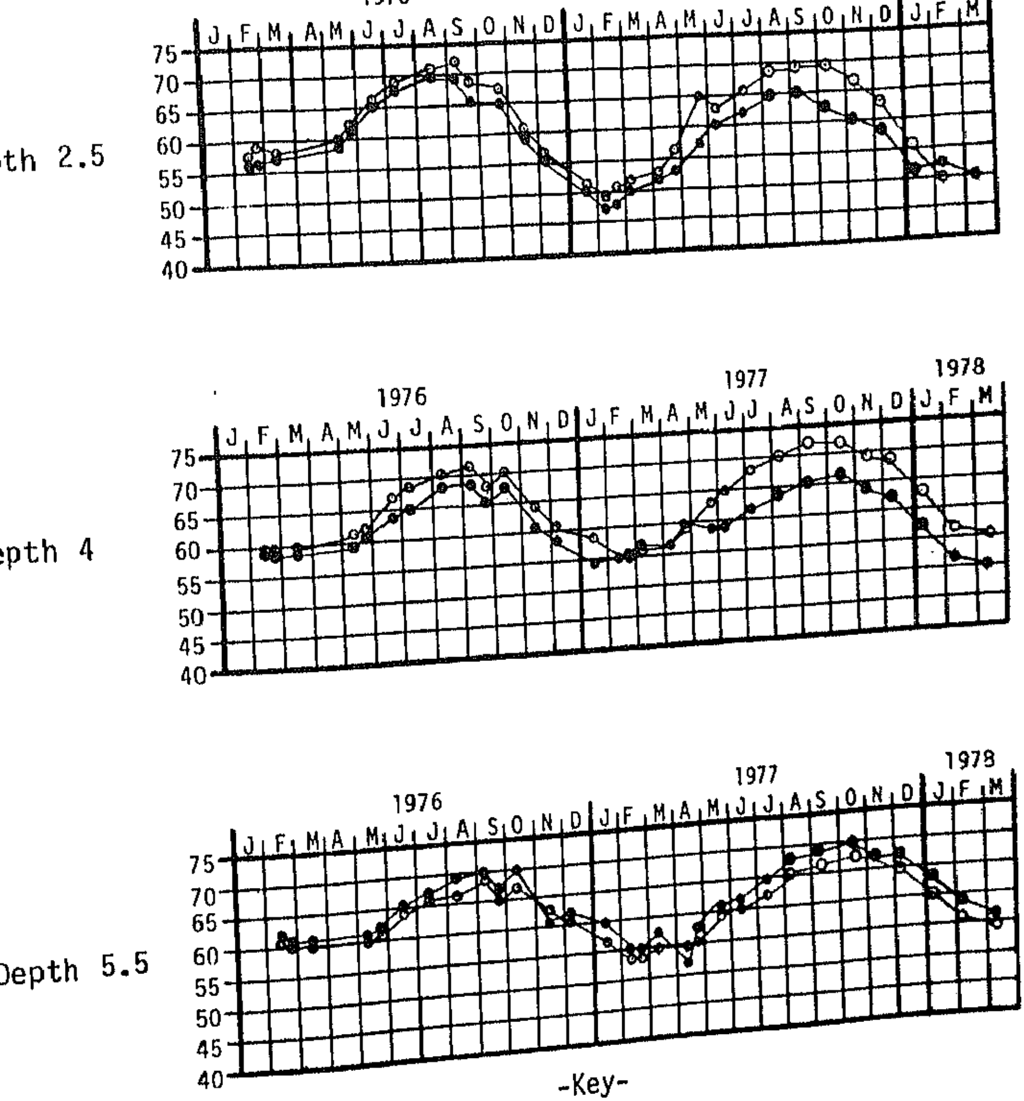
Date	Movement		
	Feet	Inches	Cm.
Mar. 16, 1976	.024	.288	.732
June 25, 1976	.099	1.188	3.018
July 7, 1976	.095	1.140	2.896
Aug. 11, 1976	.092	1.104	2.804
Aug. 24, 1976	.077	.924	2.347
Sep. 14, 1976	.055	.660	1.676
Sep. 30, 1976	.063	.756	1.920
Oct. 22, 1976	.046	.552	1.402
Nov. 18, 1976	.067	.804	2.042
Dec. 21, 1976	.078	.936	2.377
Feb. 7, 1977	.084	1.008	2.560
Feb. 21, 1977	.096	1.152	2.926
Mar. 4, 1977	.094	1.128	2.865
Mar. 25, 1977	.111	1.332	3.383
Apr. 11, 1977	.113	1.356	3.444
May 23, 1977	.135	1.620	4.115
June 9, 1977	.122	1.464	3.719
July 12, 1977	.096	1.152	2.926
Aug. 11, 1977	.116	1.392	3.536
Sep. 15, 1977	.117	1.404	3.566
Oct. 21, 1977	.111	1.331	3.383
Nov. 11, 1977	.104	1.248	3.170
Dec. 20, 1977	.104	1.248	3.170
Jan. 5, 1978	.099	1.188	3.018
Feb. 13, 1978	.093	1.116	2.835
Mar. 10, 1978	.076	.912	2.316



○ North Side Boring
● East Side Boring
△ South Side Boring
■ West Side Boring

* Refers to Depths Below Perimeter Grade Beam

Fig. 52 Soil Moisture Content - Subsurface Irrigati
System - 5807 Fess Street, Dallas, Texas



-Key-

o North and South Side Average
• East and West Side Average

*Depths refer to feet below grade beam.

Fig. 53 Soil Temperature Variation
5807 Fess Street, Dallas, Texas

3807 Fess Street, Dallas, TX

SIS

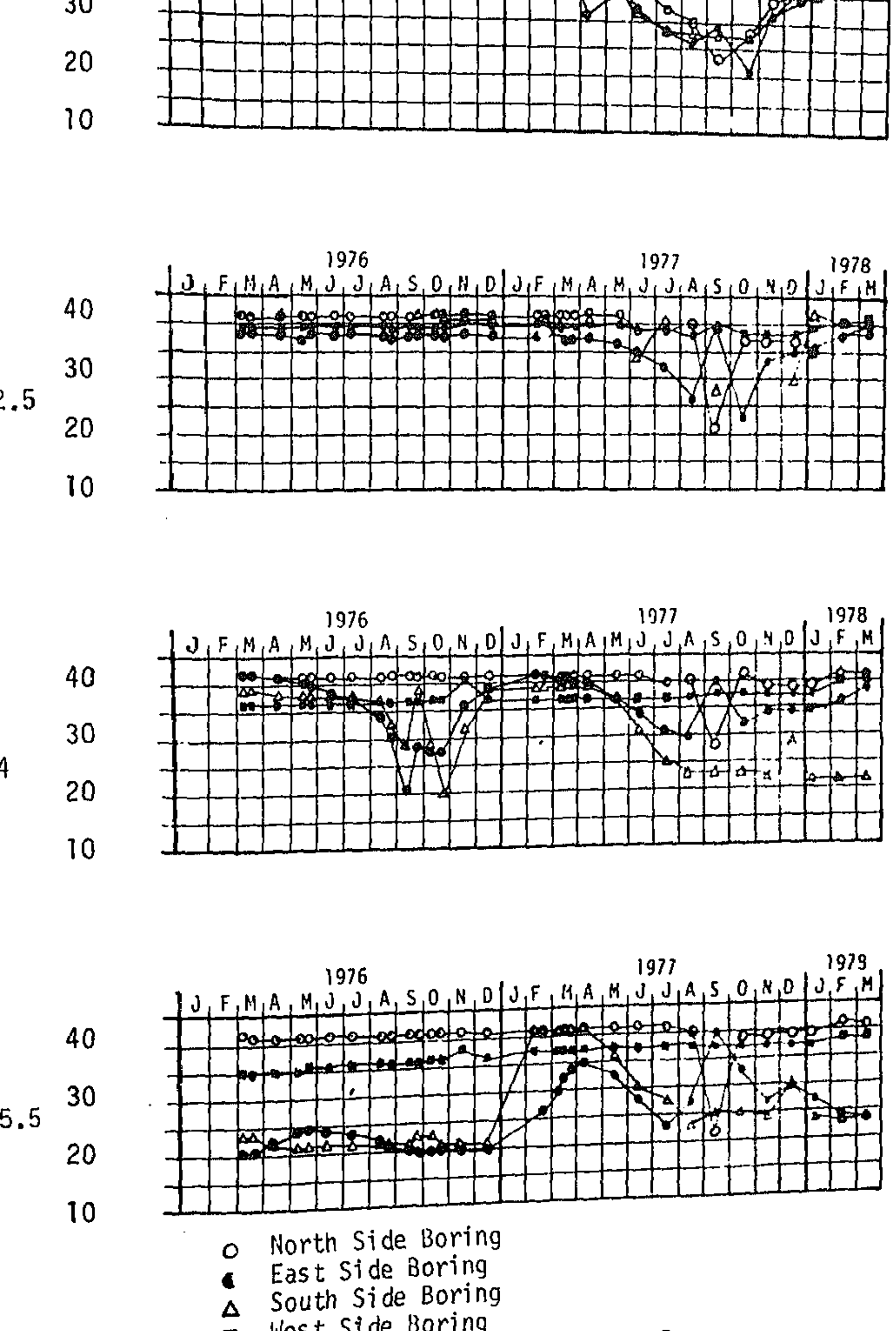
Cell Location	*Depth (ft) 1	2.5	4	5.5
North	59.45 9.14	58.20 7.28	60.85 5.82	60.20 5.02
East	63.88 8.29	62.15 6.71	59.90 5.53	61.10 4.47
South	63.25 8.55	63.55 7.15	64.83 5.58	60.95 4.58
West	60.64 8.68	55.05 7.47	59.15 5.88	63.25 5.94

3513 Heath Street, Mesqu

SIS

Location	*Depth (ft) 1	2.5
North	62.68 8.76	60.86 7.10
East	58.39 8.60	59.23 7.18
South	60.32 8.25	dead
West	63.74 7.26	62.65 5.39

*Depth refers to feet below grade beam.

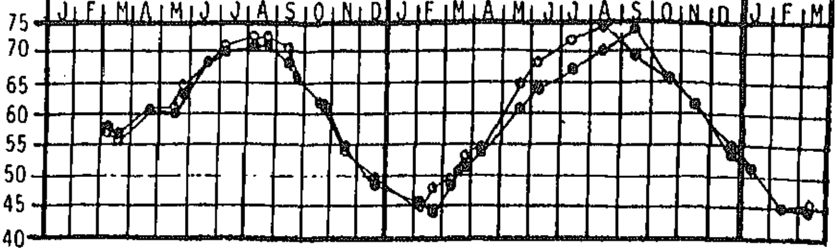


* Refers to Depths Below Perimeter Grade Beam

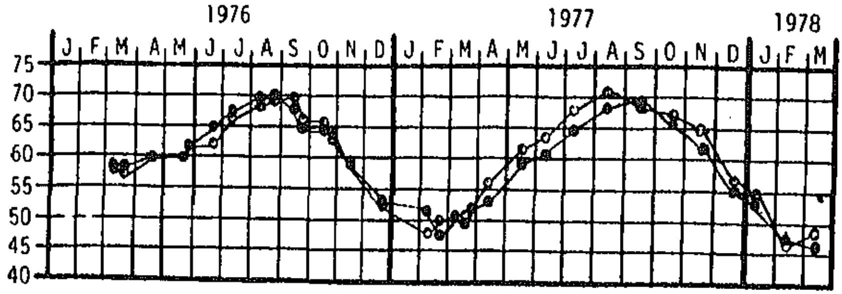
Fig. 5A Soil Moisture Content - Sub-Surface Irrigation

Soil Temperature (^{0} F)

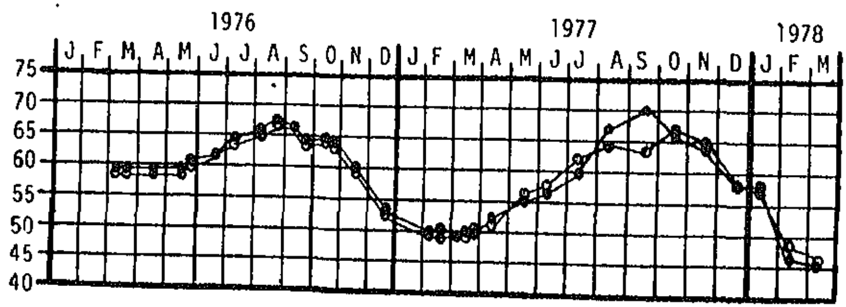
*Depth 1



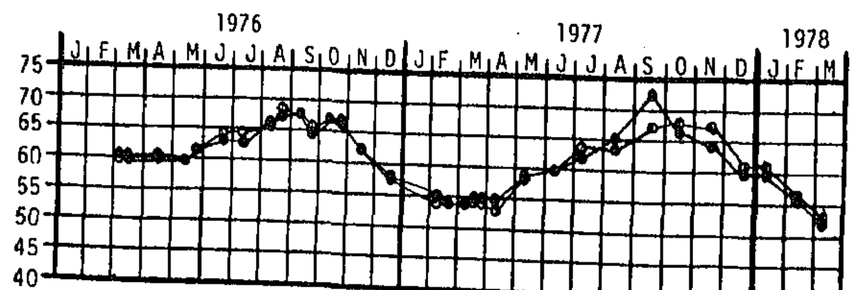
Depth 2.5



Depth 4



Depth 5.5



-Key-

o North and South Side Average...

sly been noted that this formation was dense and contained racks and fractures. Further, the soil within the depths of ined fine sand and silt materials. Consequently, water could utilizing fracture paths initially. As these avenues closed, n through the subsurface soils would depend on the soil per- adequate distribution. The mixture of silts and sands within provide the soil matrix with a higher permeability and more re migration. This condition is indicated with exceptions by or the curves indicated by depth 4, the anomaly indicated by ells on the East and West sides of the test house are considered rors. These significant variations in moisture contents within e periods and at such a depth would not occur so abruptly.

a given in Figure 54 are appropriate only for the time the sub- tion system was operative. Beyond that time, data values re- effects modified by a foundation watering program the new ouse initiated after discussion with research personnel.

erature variations with time and depth are given in Figure 55. stic shape with time and depth is again noted. The instrumen- ed in the subsoils for this test house location are operative, e subsurface irrigation system was destroyed. Consequently, w conclusively that soil temperature may be considered a imatic temperature cycles and moisture movement into or out of s little, if any, effect. The values for temperature means and tions are given in Table 33, page 118.

mparison of Moisture-Temperature Characteristics

premise in the use of a subsurface irrigation system as a sub- ation technique for expansive clay soils was to install and system which would introduce water into the subsoil at initially es which would deminish as soil moisture demand was satisfied. ld be available for the soil, if required, but would not be e soil under pressure.

s investigation established among the index properties an al moisture content of 24.2 percent at the test house at 5807 Dallas, Texas. The average Plastic Limit was 24.5% with a mini- content below the Plastic Limit of approximately 5%. The nt of Montmorillonite clay mineral was 25.8%. All of these or a soil depth of five feet. The relatively close insitu er content and Plastic Limit again illustrates the effectiveness ffects in causing the soil to give up and take in significant ter as indicated in Figure 52, page 116. It is also noted that

cottonwood tree at the Northeast corner of the house augmented climatic effects in taking a significant percentage of water from the soil.

The effects of climate are not as extreme at the test house at 3513 Heath Street, Mesquite, Texas. The soils investigation established among index properties a natural moisture content of 29.5%. The average Plastic Limit was 31.8% and the maximum deviation of moisture content was 15%. These values are for the upper five feet of soil. It should be noted that the deviation of moisture content given was for the upper one foot of soil. Below the depth the average moisture content of the soil was 32.3 or slight above the average Plastic Limit of 31.8%. The average percent of moisture was 32.3 within the depths of interest of the soil. As the subsurface irrigation system was installed at the approximate depth of moisture defici it would follow the moisture content would be raised to the soil moisture demand requirement and remain stable while the system was operative as show by Figure 54 , page 119. At other depths of interest, more variation occur however, as the natural moisture content existed above the Plastic Limit the demand would be less. This variation, at the lower depths, while the system was in operation, could be caused to some degree by climatic effects but may be primarily due to variations in subsoil properties.

A comparison of the variation in subsoil temperature with time and dept for the two test houses indicate excellent agreement as shown in Figures 53 and 55 pages 117 and 120 . These two test houses are separated by a number of miles and located on different geologic formations which supports the conten tion that variations in soil temperatures and the insulating properties of soil are a direct function of climatic temperatures. Tables 32 and 33 , page 121, give the values of temperature means and standard deviations at ll depths of interest for these two test houses.

.3 EVALUATION OF SUBSURFACE IRRIGATION SYSTEM STABILIZATION

The primary purpose for use of the subsurface irrigation stabilization echnique was to determine if a relatively low cost system could be utilized long with the known characteristics of expansive clay soils to inhibit or mi ate volume change due to climatic conditions. This would limit volume chang nd accompanying differential movements in the perimeter subsoils. As ex- vation would be a minimum for installation, much of the work involved could accomplished by a home owner who is experiencing damage to his house by rtical movements associated with expansive clay soils.

For this stabilization process, water was not introduced into the foun- tion soils by intent. It was desired to determine if the expansive soils uld imbibe sufficient water to reach an equilibrium condition and then only ke water from the system as necessary to fill the moisture demand of the so e concept as developed would appear to be valid, and damage reversal could initiated for house slab movements where the perimeter beam is lower than e slab interior. The two test houses ...

for this technique. Consequently, it was established that com-
ation of the subsoil was not possible with this technique.
movements above and below an equilibrium or stabilization con-
atively small, they are not totally eliminated.

e a number of problems associated with the use of this stabili-
ue. One of the problems was a control system for water pressure
ow. For this technique to be viable, the system would essen-
be tamper proof. Another problem for consideration would be
terrupted water service to a house having this type of subsoil
system. During the period of this research program, water ser-
rupted on many occasions, and the system was essentially de-
e test house at 5313 Heath Street, Mesquite, Texas. Finally,
r of this porous rubber pipe has gone out of business in the
th area and it is not known if any source of supply exists.

for utilizing this stabilization technique are relatively low.
neal foot of house perimeter at 5807 Fess Street, Dallas, Texas
cost per lineal foot of house perimeter at 3513 Heath Street,
was $3.78. Both cost figures could be reduced significantly
accomplishing the excavation and backfilling required to bury
the perimeter.

ferential movements associated with climatic effects were
a sufficient market could be developed to warrant manufacture
ipe, then perhaps additional consideration could be warranted.
owever, the use of porous rubber pipe as a subsoil stabiliza-
is not justified.

SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The primary objective of this reasarch project, identified as Phase HUD Contract H-2240R, was to investigate certain remedial techniques whi could be used to restore houses damaged by foundation movements caused b expansive clay soils. All techniques were directed towards stabilizing mass of soil beneath the house floor slab to a depth of five feet or mor Both equipment and materials utilized for the subsoil stabilization techn ques investigated were readily available to a contractor to determine eco nomical alternatives. Further, consideration was given to certain techni and to portions of the work a homeowner could accomplish to reduce costs protect his investment.

The ten (10) houses included in this investigation were HUD owned pr erties that were sold upon completion of actions associated with a remedi technique. Deed restrictions permitted continued data acquisition for th duration of the contract. The houses included in this study were identif by the HUD Dallas Area Office, and all were severely distressed by vertica movement of the foundation soil resulting from volume change. The amount volume change was largely a function of the expansive clay soils of a par- ticular geologic formation and the climate of the area.

The Dallas-Fort Worth metroplex area has a semi-arid climate. Length hot and dry periods with little or no rainfall followed by cool or cold we periods provide the environment for expansive clay soils to manifest their destructive shrink and swell properties.

Five of the houses in this investigation were sited on the residual clay soils of the Eagle Ford geologic formation and the other five were located on the residual clay soils of the Taylor geologic formation. Both geologic formations are noted for their expansive clay soils. Further, the residual clay soils for both formations are from the Gulf Series of the Cretaceous Age and are neritic marine deposits. Volcanic materials are prominent and in particular the high percentage of Montmorillonite Clay minerals at shallow depths formed by weathering of ash.

The success, or failure, of a particular soil stabilization technique in mitigating soil volume fluctuations in the foundation subsoil was a time dependent process. Data acquisition continued over approximately two years or four seasonal climatic cycles, at which time a determination was made of the effectiveness of each technique. A stable condition was being approache for the subsoil if apparent behavior would allow the ...

a minimum volume configuration.

wing comments summarize the relative effectiveness of each
ilization technique to minimize volume change of the expansive
the two geologic formations.

e Slurry Pressure Injection: If for no other reason the high
his technique makes it uncompetitive with other methods. The
lineal foot of house perimeter was $26.49 for the house at
32nd Street, Grand Prairie, Texas, and the cost per lineal
ne house perimeter was $28.27 for the house at 2710 Cary Drive,
Texas. The large differential movements and soil moisture
luctuations with climatic conditions, and without a lag time,
a barrier to inhibit moisture migration was not provided. This
er justified by comparing moisture data from the instruments
in a boring placed well outside the injected area, with
content variations from instruments inside the injected area.
uments were placed at equivalent depths in the soil. It was
that the lime slurry pressure injection process was not an
stabilization technique for houses damaged by expansive clay

illary Barriers: The use of this technique for stabilization
tion subsoils for homes damaged by expansive clay soils appeared
iable technique. A definite factor in favor of this method was
asing amount of cost reduction possible depending on the amount
homeowner would contribute. The ultimate situation would
re the services of a trenching company to dig the narrow
excavation around the house and delivery of graded capillary
terial. A summary of performance of this stabilization techni-
ell as other vertical moisture barriers is given in Table 27, page
values given are maximum values for January 1978, for comparison
Detailed review of this technique as presented in Section 4 is
The figures on vertical movements around house perimeters
niformity of movement between leveling points, and for the test
Cedar Keys Drive, Lewisville, Texas, the cost for installation
abilizing technique was only $3.31 per lineal foot of house
For the test house at 9909 Bluffcreek, Dallas, Texas, the
3.71 per lineal foot of house perimeter. It is noted that
n are first time application costs for this research effort.
ed previously, these costs would be reduced due to the increased
y of trenching equipment now available.

viable technique. A certain ... homeowner participation, primarily involving removal of spoil resulting from the excavation process. To install this vertical barrier, as accomplished in this research program, specialized equipment is essential. Consideration is warranted for a simpler formulation of barrier mixture. The basic material of chopped-up rubber tire carcasses would still be considered as the basic aggregate, however, testing for other binding agents needs to be accomplished. Particularly, an alternate material to emulsified asphalt needs to be developed since it is expensive and difficult to work. The primary objective is relative impermeability. The strength of the membrane is not an essential consideration.

Table 27, page 101, show data values for the houses treated by this stabilization technique as the maximum values for January 1978. Data showing variations of foundation movements with time indicate the techniques effectiveness. The relative uniformity of vertical movement between leveling points around the house perimeter are indicative of technique effectiveness. These data are reinforced by the figures relating to subsoil moisture content variations with time and depth. Data reflecting narrow band widths with time, for all depths of interest, indicate relative stability, or negative influence of the climatic cycles. For the test house at 461 Sweetbriar Drive, Lewisville, Texas, the cost of the rubber barrier was $5.41 per lineal foot of house perimeter. For the house at 1314 Athens Street, Mesquite, Texas, the cost was $5.79 per lineal foot of house perimeter. Again, the costs given could be reduced by use of modified trenching equipment now available to the building industry.

The introduction of water to the foundation subsoils surrounded by a rubber vertical barrier could be accomplished by a homeowner. A small diameter hole could be punched through the barrier at intervals. A commonly available root feeder injection lance could be inserted into the subsoils beneath the perimeter beam for water injection. As numerous applications of water would be required, the holes could be temporarily plugged by tapered wooden dowels. After relative stability is achieved, the holes could be permanently sealed with a rubber caulking compound.

...rt vertical moisture barriers. The use of a lean concrete
...ture barrier to mitigate climatic effects and attendant
... of foundation subsoils was considered to be a viable stabili-
...que. A limited amount of homeowner cost reduction could be
...by removal of spoil material from trench excavation. The
...al could be installed more effectively by utilizing readymix
...s equipped with extended delivery chutes. Strength is
...mpermeability, so a low cement ratio could be utilized with
...ers to insure sufficient fines in the mix for a minimum void
...ould insure a minimum cost to the homeowner.

...es from Table 27 for the two houses using this stabilization
... the maximum values for January 1978. All values given in
...hown for comparison. However, the data values varying with
...cal movements and differential movements are given in detail
...nd indicate the technique effectiveness. The uniformity
...vements between leveling points around the perimeter of
... excellent performance indicators. This performance is
...med by the figures indicating the stability of subsoil
...nts with time at all depths of interest.

...ouse at 1137 Eastwood Drive, Lewisville, Texas, the cost
... this technique was $4.75 per lineal foot of house perimeter.
...at 4204 Culmer, Balch Springs, Texas, the cost was $4.54
...t of foundation perimeter. These costs would be reduced
...easons given in Paragraph c.

...duction of water into the foundation subsoils could be
...y the homeowner in a similar manner as that described for
...tical barrier discussed in Paragraph c above. However,
...adding water would be drilled through the barrier or pre-
...lled dowels while the concrete was still plastic.

...e Irrigation System: The installation of the subsurface
...tem to stabilize the subsoils beneath a house subjected
...vements resulting from soil volume changes induced by
...tions was not completely effective. Differential movements
...tively stable value and vertical movements become rela-
... around the house perimeters, but climatic effects are
...l. The magnitudes of vertical movement would appear to be
...inimum, but the floor slab will undergo flexure which
...imatic changes.

... low cost system for which the cost of installation could
...y reduced by a homeowner. This would include all excava-
...illing labor required to install the system. The house at
...t, Dallas, Texas, cost $2.70 per lineal foot of house
...for the test house at 3513 Heath Street, Mesquite, Texas,

Considerable difficulty was experienced during the period of t
study in keeping the system in operation at both test houses. Ther
were indeterminate periods of time when outages occurred at each lo
tion due to vandalism, water shutoffs, and ultimately system destru
during August 1977, for the house at 3513 Heath Street, Mesquite, T

The subsurface irrigation system must be considered an active
opposed to a passive system as discussed in paragraph b, c, and d a
as mechanical components are required to function properly for a su
cessful system. This was found to be undesirable as there are too
ways to tamper with, or defeat the system. There are too many prob
inherent in such a system at this time, and climatic cycle influenc
still is associated with the foundation subsoils. The subsurface i
gation system cannot be considered a realistic stabilization techni
for houses damaged by expansive clay soils.

For all techniques discussed in paragraphs a through e above, data a
ition has continued over approximately two years or four seasonal clima
ycles. These data include vertical movements referred to a permanent b
ark, subsoil moisture at various depths and subsoil temperature at equi
epths. By various presentations or interpretations of data, it was app
hat achieving soil stability was a time dependent process, as was the d
ondition associated with the shrink and swell process of expansive clay

.2 CONCLUSIONS

This two year study of methods to restore houses damaged by actions
ssociated with expansive clay soils to a usable condition indicates cer
entative conclusions.

House and yard maintenance were considered directly related to the m
itude of house damage caused by differential vertical movement. The ma
f these movements is a time dependent process which is influenced by th
everity or extremes of the climatic cycle. This influence can be modif
y providing adequate water to areas around the house. The amount of wat
r the necessary watering program would be dependent on those sides of th
ouse subjected to the greatest severity of the climatic drying cycle and
ocation and number of trees.

The addition of water to foundation subsoils was not and could not b
xpected to completely eliminate prior movements associated with shrink a
well actions. This process is not a linear type relationship, and as th
ype soils shrink a reorientation of the clay minerals occurs. When a sw
ng cycle is initiated, water will be taken into the double layer of the
ansive clay minerals. However, these minerals will not return to their
riginal positions due to some interlock of soil particles and the inhere

... as a layered system. The barrier depth was limited
shed by the availability of trenching equipment. Consequently,
question whether a deeper barrier would function better, or a
a shallower depth with reduced cost would perform as well as those
Further, it was concluded that other type barriers utilizing other
er material could be developed which would also accomplish the in-
pose. However, this research effort was to utilize common materials
ques by which the cost could possibly be reduced by homeowner par-
. It is not believed, that the capillary barrier will be a deter-
ot systems from trees crossing the barrier to obtain desired mois-
the foundation subsoil.

the results of this research it was concluded the use of a vertical
apillary or relatively impermeable, is a viable concept to stabilize
subsoils from volume changes resulting from climatic cycles. Along
arrier, the moisture content of the subsoils must be raised the
3 percent above the average Plastic Limit of the subsoils down to
of the barrier. This action will place the mass of subsoil in a
able moisture regime whereby the volume change of the soil mass
ess than five percent of its total potential. The addition of
he subsoil will cause the soils to increase in volume and displace
erimeter upwards. Low perimeter edges would be the normal distress
his area. The amount of time for the soil mass encompassed by the
reach a stable condition is a function of the expanive soil pro-
d how fast the added water will diffuse through the soil to approach
rium condition. The end result would be for the damaged house and
soil to behave as a single entity whereby this condition would be
o remain essentially constant. This would permit cosmetic repairs
cted, both inside and outside the damaged structure, and restora-
usable condition.

Interim Report of Remedial Measures for Houses Damaged by Expansive
Department of Housing and Urban Development, Office of Policy Develo
and Research; Division of Energy, Building Technology, and Standards
Wasington, D. C., October, 1975.

Interim Report of Remedial Measures for Houses Damaged by Expansive
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and Research; Division of Energy, Building Technology, and Standards
Washington, D. C., November, 1976.